IMPLEMENTING A PROCTORED ALEKS-BASED ADAPTIVE LEARNING STRATEGY TO EVALUATE STUDENT PREPAREDNESS AND PREDICT SUCCESS IN CALCULUS I AT THE UNIVERSITY OF ALASKA FAIRBANKS

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ABSTRACT

In Fall 2016, the Department of Mathematics and Statistics (DMS) at the University of Alaska Fairbanks (UAF) initiated a study to determine if the Assessment and LEarning in Knowledge Spaces Placement, Preparation, and Learning test (ALEKS PPL), given under proctored conditions, can be an effective tool for measuring student preparedness and predicting success in Calculus I while controlling for enrollment and demographic information. The study includes 583 students who took a Calculus I course in Fall 2016, Fall 2017, Spring 2018, Fall 2018, Spring 2019, and Spring 2020 semesters and took a Proctored ALEKS PPL test (PAPL). Of the 583 students, 301(52%) students obtained at least a score of 75 on the PAPL test, and 338 (58%) were successful in the Calculus I course. The average score on the PAPL test was 13 points higher for the students who had been successful in Calculus I ($P < 0.0001$, Welch's t-test). Logistic regression showed that each additional score on the PAPL test was associated to increase the odds of success in Calculus I by a factor of 1.0843, or 8.43%, when all other factors were fixed (95% CI: 1.07 – 1.1, $P < 0.0001$). This study recommends implementing the PAPL test as an adaptive learning tool and a requirement for Calculus I at UAF and establishing a student-centered standard to address the student knowledge gap in precalculus.

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1. INTRODUCTION

Improving success rates in first-year mathematics courses is imperative because of the nation's pressing demand for Science, Technology, Engineering, and Mathematics (STEM) graduates [1]. Calculus is considered a gatekeeper for almost all STEM fields [1, 2, 3]. Therefore, Calculus, particularly Calculus I, is a topic of national concern as universities attempt to increase enrollment in STEM fields. Enrollment in Calculus I at four-year colleges and universities in the U.S. increased significantly from Fall 2005 (over 201,000) to Fall 2010 (over 234,000) to Fall 2015 (over 255,000) (not including distance-learning and dual enrollment students) [4]. Adequate preparation, e.g., precalculus, is essential for student success in Calculus I and subsequent courses. The math background of students taking college-level Calculus I varies widely, for example due to differences in the level of rigor in math education among high schools, two-year and four-year colleges and universities. Accurate assessment of student preparation is essential to correctly advise students into Calculus I and thereby improve the chances of success in the mathematics necessary for STEM majors.

Several mathematics and statistics education studies have examined poor performance in mathematics at the high school level [5, 6]. A National Center for Education Statistics (NCES) report [7] shows that many high school graduates do not have sufficient preparation for college-level math courses. Such students, therefore, often take remedial or developmental courses in college. Most post-secondary institutions offer remedial courses for academically less-prepared students in college-level classes. A 2016 NCES study [8] on remedial education reported that between 2003 and 2009, 59.3% of students at public two-year institutions and 32.6% of students at public four-year institutions took at least one remedial math course. However, the student success rates in remedial classes are low [9].

Due to nonuniformity among institutions in college-level course curriculum, it is often challenging for educators to identify the students who need to complete required remedial courses. In addition, educators have had an ongoing debate about whether it is appropriate to force students to take remedial courses. Many argue that the probability of graduating from a four-year college is low for students with poor high school preparation unless they take necessary remedial education. Other critics describe this situation as a "hoax" and argue that forcing students to take remedial courses may demotivate them and lead them to give up and drop out [10].

Remedial education continues to be a topic of debate. Recent studies and policies are mixed and inconclusive. In 2013, the state of Florida, under the Senate Bill 1720, made placement exams and remedial education optional for many students [11, 12, 13]. A 2016 study by the City University of New York (CUNY) did not find evidence that students who enter college needing remedial courses are less likely to graduate than students with no such need [14]. Effective from the Fall 2018 semester, all 23 California State University campuses removed math remedial course requirements [15]. On the other hand, a Tennessee study in 2019 found that remedial education was effective in helping students pass college-level math courses [16].

Classifying and putting students into a college-level course based on placement test scores is often considered inaccurate and is also the subject of ongoing debate [14]. In the 1980s, several community colleges used placement test scores to force students to take remedial courses. In 1988, the Mexican American Legal Defense Fund (MALDEF) filed a lawsuit against this policy. The MALDEF lawsuit was settled in 1991 and instructed community colleges to provide evidence to support their remedial course enrollment policies based on placement test scores [17, 18].

The Harvard-Smithsonian Center for Astrophysics conducted a large-scale study that combined data from 132 U.S. institutions and 5,507 students enrolled in Fall 2009 [19]. The study examined student success in college-level calculus to measure the effects of taking college precalculus. They reported that taking college precalculus does not help students earn higher grades in subsequent college calculus courses [19].

In recent years, the application of adaptive learning has increased significantly for identifying student knowledge gaps in relevant prerequisite courses [20, 21]. Assessment and LEarning in Knowledge Spaces (ALEKS) is an artificially intelligent adaptive learning program that uses adaptive problem solving to determine students' precise level of knowledge in subjects including mathematics, chemistry, statistics, and accounting [22]. The ALEKS Placement, Preparation, and Learning test (ALEKS PPL) with precalculus curriculum contains 251 topics and typically asks 29-32 questions [23].

Instead of remedial courses, post-secondary institutions are increasingly interested in implementing ALEKS PPL as an adaptive tool for evaluating student prior knowledge and preparing students for college-level courses. The Mathematical Association of America (MAA) conducted the first-ever nationwide study of college-level Calculus I that combined data from 213 colleges and universities, 502 instructors, and more than 14,000 students from Fall 2010 in the U.S. The study reported that among PhD-granting universities that offered a placement test (N = 58), 10% of them used the ALEKS placement test. The study also stated that most post-secondary institutions used placement tests to place students into Calculus I in order to increase the passing rate [3, 24].

However, the effectiveness of measuring student preparedness with placement tests is mixed. A study of first-semester calculus students showed that the MAA Maplesoft test was a strong indicator of subsequent student success [25]. However, a 2012 study based on data from the Statewide Community College System (SWCCS) reported that Accuplacer and Compass placement test scores are not good in predicting student success in college-level gatekeeper math courses [26].

In this study, we measure student preparedness using a proctored ALEKS PPL test. The ALEKS corporation has published a long list of universities using the ALEKS PPL test for placing their students. For example, the University of Northern Iowa conducted a study involving 2,500 students in the academic years of 2011-2012 and 2012-2013 [20]. They found that D/Fail/Withdraw (DFW) rates dropped by 20% in Calculus I after the introduction of the ALEKS PPL test for placement [20]. In Summer 2012, the Oklahoma State University conducted a study involving 7,000 students to measure the effectiveness of implementing the ALEKS PPL test. They found that in Calculus I, DFW rates dropped by over 10% [20].

In 2001, the Louisiana Tech University (LTU) began using ALEKS for online math tutoring and made it mandatory for students who intended to take Calculus I [27, 28]. They conducted two studies to compare ALEKS and ACT math scores as predictors of student preparedness and success in Calculus I. They found that ALEKS scores were a better indicator of Calculus I preparedness than the ACT math score [27]. However, they found no evidence of substantial improvement in student success in Calculus I after incorporating the ALEKS assessment score into the math placement process [28].

At the University of Illinois (UI), the ALEKS-based placement mechanism was found to be more effective than the previously used ACT-based mechanism [29]. UI began using ALEKS in the summer of 2007 as a basis for placement in first-year math courses. The study collected unproctored ALEKS PPL test scores for approximately 10,000 Fall 2007, Spring 2008, and Fall 2008 students. After implementing the ALEKS PPL test, they found that W grades in Calculus I dropped by over 49% in 2007 and over 81% in 2008 compared to 2006 [29].

Like UI, in the fall of 2008, Boise State University (BSU) adopted the unproctored ALEKS test for the first time as a math placement strategy for Precalculus and Calculus I [23]. The cut scores were the same for both UI and BSU, 40% for Precalculus and 70% for Calculus I. Students who failed to achieve the cut scores by the end of add/drop period, which was their first assignment worth 10% of their grade in the upcoming course, had the option to self-select down one math level instead of receiving a zero in the first assignment. This strategy was found effective at both universities. At UI, only 1%, and at BSU, only 1.5% of students decided to remain in the course knowing that they were not ready for the course and had already received a zero on their first assignment. After implementing the ALEKS test, BSU improved the success rates for Precalculus and Calculus I and made it a course requirement [23].

The Michigan Technological University (MTU) has been using the ALEKS PPL test for placing students in the first math course since Fall 2014 [30]. A study was conducted based on Fall 2015 enrollment in three first-year math courses. The study used unproctored ALEKS PPL test scores. The published results in 2017 stated that "...students who place into Calculus I on their first testing attempt are the most likely to be successful in the course." [30].

Universities outside the U.S. have also studied ALEKS PPL for placement. A University of Manitoba (UM) study collected ALEKS PPL data for 462 students who completed the Introductory Calculus course in Fall 2016 [31]. The study examined student success in Introductory Calculus while controlling for student preparedness measured by ALEKS test scores and high school math grades. In 2019, the study reported that ALEKS test scores were a better predictor of student success for Introductory Calculus than their high school math grades. The study recommended using the ALEKS test as a placement test for college-level calculus at UM [31].

At UAF, in each academic year, on average, 225 students take the Calculus I course offered by DMS at the Fairbanks campus and eCampus. Typically, unproctored ALEKS PPL scores are used for math placement. In Fall 2016, the DMS leadership initiated a study to determine if the ALEKS PPL test, given under proctored conditions, can be an effective tool for identifying well-prepared students for Calculus I. Historically, DFW rates in Calculus I at DMS have been high. The motivation of the study was to improve advising and identify students who may benefit from additional resources.

Data on student achievement in Calculus I were collected for six semesters, three Fall semesters (Fall 2016, Fall 2017, and Fall 2018) and three Spring semesters (Spring 2018, Spring 2019, and Spring 2020). In order to reduce variation in student grades due to differences in assigned work and grading styles, the department decided upon some regulations for evaluating student performance and achievement in Calculus I. With the exception of the Fall 2016 semester, all sections of Calculus I were taught with a coordinated class structure. For in-person sections, this meant that all assessments including homework assignments, quizzes, midterm exams and final exams were identical among sections and developed by a consensus of the Calculus I instructors in each given semester. Moreover, all assessments were graded communally, with graders from each section grading a portion of each assessment. The online sections adopted the same course structure but were less tightly coordinated and only required midterms and the final exam be proctored. In the online setting, 58% of a student's grade was based on proctored assessments compared to 88% in the in-person setting. For all semesters in the study students were required to take a Proctored ALEKS PPL test (PAPL) during the second week of the semester. The score on the PAPL test constituted roughly 3% of the course grade.

Analysis of student success should be a multi-dimensional study. Besides student academic performances and achievement, enrollment status (e.g., in-person/online, STEM/non-STEM, bachelor/non-bachelor, enrolled credit hours, dual enrollment, full-time/part-time) and demographic factors (e.g., sex, age, race, ethnicity, income status, first-generation) may play an important role in predicting academic success [32]. Therefore, student enrollment status and background information also need to be studied while analyzing academic success.

In this study, we analyzed the data aiming to find the answer to our following primary research question:

> At UAF, how well does the proctored ALEKS PPL test measure student prior knowledge of precalculus content and predict success in Calculus I, after controlling for enrollment and demographic information?

This study examined student preparedness, in terms of a current ALEKS PPL test under proctored conditions, and student success in Calculus I while controlling for enrollment and demographic information. Note that students were *placed* into Calculus I based on their prerequisite coursework, unproctored placement test, or AP scores. The goal of the study was to determine if PAPL scores were good predictors of success in Calculus I. We examined the association between student preparedness as measured by PAPL scores and success in Calculus I. We also investigated whether average preparedness changed over the semesters in the study.

Our study differs from other related studies on student preparedness and success in Calculus I in several ways. Our study was based on a single-unit PhD-granting research university, UAF. Our study included mostly coordinated Calculus I courses over six semesters, which allowed us to examine the semester-to-semester variation in student performances. Also included in our study are students who took Calculus I through distance learning and with dual enrollment status (i.e., K-12 college-level course taking students).

Most importantly, students in our study took the ALEKS PPL test while being proctored. A 2010 Michigan State University (MSU) study compared the effectiveness of proctored and unproctored mathematics placement tests [33]. The study reported that unproctored placement tests often inappropriately evaluate student preparedness for college-level math courses. The study recommended using a proctored placement test over the unproctored one [33].

Our study considered student PAPL test scores to measure precalculus content knowledge for college-level Calculus I. Based on our findings, we recommend some potential areas of further investigation to measure the effectiveness and appropriateness of implementing the PAPL test as an adaptive learning tool and a course requirement for college-level Calculus I at UAF.

2. DATA AND METHODS

The study included 583 students who took a Calculus I course in the Fall 2016, Fall 2017, Spring 2018, Fall 2018, Spring 2019, and Spring 2020 semesters and took a PAPL test. We collected each student's Calculus I grades from DMS. Student enrollment (e.g., course delivery method, STEM, primary degree, enrolled credit hours, dual enrollment status) and demographic (e.g., sex, age, race, ethnicity, income status, first-generation status) data were collected from the UAF central student database.

In our initial dataset, we had more than 670 observations. While processing the data, we noticed two inconsistencies. First, around 10% of students previously took Calculus I at DMS. Since repeated observations on the same student are not independent, we only included data related to each student's first attempt. In addition, the data set included twenty-six students with a score of 0 on the PAPL test, indicating that these students did not take the test or started the test and did not finish it. As these zeros represent missing values rather than actual measures of student preparedness, we excluded these twenty-six records.

To give some perspective, ALEKS suggests the cut score for Calculus I be set in the mid 70's and the cut score for Precalculus be set around 60 [34]. At UAF, the cut score for the unproctored ALEKS PPL assessment is 78 and a cut score between 55 and 65 for precalculus courses depending on the type of course. For ease of communication in this document, we say a student is *well-prepared* if the student achieves a score of 75 or higher on their PAPL test. We say the student is *less-well-prepared* if the student achieves a PAPL score below 75.

We defined several dichotomous variables based on student enrollment information and course outcomes in Calculus I. Students were designated as successful in Calculus I if they earned a grade of C- or higher. Additionally, data regarding student race were categorized as White, non-White, and undisclosed. An ethnicity variable was defined to identify Hispanic students.

We prepared a summary table for students taking Calculus I to understand their enrollment patterns and demographic characteristics. We counted the number of well-prepared and less-well-prepared students for each factor level (e.g., male vs. female). We computed the true-positive and false-negative rates to perform a comparative analysis between different factor levels. The true-positive rate was computed as the proportion of well-prepared students who succeeded in Calculus I. The false-negative rate was computed as the proportion of less-well-prepared students who succeeded in Calculus I.

To measure the overall effectiveness of the 75% cut-score of the PAPL test to identify student outcomes in Calculus I, we computed the accuracy rate, false-positive rate, and false-negative rate [31, 35, 36]. The accuracy rate was computed as the total proportion of true-positive and true-negative students, i.e., the proportion of well-prepared students who succeeded and less-well-prepared students who failed. The false-positive rate was computed as the proportion of well-prepared students who failed in Calculus I. In addition, we computed the mean PAPL test score with the standard deviation, Pearson's correlation between the PAPL score and Calculus I grade, percentage of well-prepared students, and success rate in Calculus I. We computed the above quantities for each semester and total students, and we performed a semester-to-semester comparison of student preparedness and course outcomes.

To assess whether student preparedness changed throughout this study, we used a simple linear regression (SLR) model to examine the linear association between the PAPL test scores (response variable) and semesters (predictor variable). We converted the semester to a numerical variable ranging from 1 to 11, i.e., 1 for Fall 2016 and 11 for Spring 2020. We examined the significance of the slope parameter and performed diagnostics to evaluate the model assumptions [37].

We examined the association between PAPL test and enrollment, and demographic factors to determine whether the mean score on the PAPL test differs among levels of a factor (e.g., male vs. female). For factors with two levels, we applied Welch's t-test [38]. For factors with more than two levels, we applied a one-way ANalysis Of Variance (ANOVA) along with Tukey's method for pairwise comparison [38, 39].

We used logistic regression to evaluate factors influencing the probability of student success in Calculus I. For a dichotomous response variable Y, with a value 1 indicating "success" and 0 indicating "failure", the logistic regression model is given by [40]

$$p(\mathbf{x}) = \mathrm{Prob}(Y = 1|\mathbf{x}) = \frac{e^{\beta^T x}}{1 + e^{\beta^T x}}$$

Where $\mathbf{x} = (1, x_1, x_2, \ldots, x_p)^T$ is a vector of explanatory variables and $\boldsymbol{\beta} = (\beta_0, \beta_1, \beta_2, \ldots, \beta_p)^T$ is a vector of regression coefficients. The logistic regression function is linearized by the logit, or log odds, transformation,

$$\mathrm{logit}(p(\mathbf{x})) = \log\left(\frac{p(x)}{1 - p(x)}\right) = \boldsymbol{\beta}^T \mathbf{x}$$

A regression coefficient in $\boldsymbol{\beta}$ that is significantly different from zero indicates that the corresponding predictor variable influences the log odds, and therefore the probability of success. We considered the following predictor variables in our model: PAPL test score, course delivery method (in-person or distance), degree (bachelor or non-degree/associate/certificate), student credit hours, dual enrollment (yes or no), STEM major (yes or no), sex (male or female), age, race (White, non-White, or undisclosed), ethnicity (Hispanic or non-Hispanic), first-generation (yes or no), and low-income (yes or no). An interaction between STEM and sex was also included to investigate whether the effect of STEM majors on the probability of success differs between male and female students.

Estimated logistic regression coefficients were used to compute an odds ratio for each predictor variable. We computed the odds ratio by exponentiating the regression coefficient for a given predictor. This value represents the multiplicative change in the odds of success for a one-unit increase (i.e., continuous predictor) or one-step change (i.e., categorical predictor) in that predictor, given fixed values for all other predictors in the model. For example, an odds ratio equal to 1 indicates no change, an odds ratio greater than 1 indicates an increase and an odds ratio less than 1 indicates a decrease in the odds of success for a one-unit increase or one-step change in the associated predictor. We used Wald tests to test the significance of odds ratios [40].

We used a three-stage modeling process to examine the effect of PAPL test scores on the probability of student success in Calculus I. In the first stage, we included only the PAPL test score as a predictor variable to examine its effect on the probability of student success in Calculus I. In the second stage, we added enrollment factors to examine the effect of PAPL test scores while controlling for enrollment factors. In the third stage, we added demographic factors along with the interaction term between STEM and Sex to examine the effect of PAPL test scores while controlling for enrollment and demographic factors.

We assessed model adequacy using standard diagnostic tools for logistic regression, including analysis of Pearson and deviance residuals and identification of influential points using Cook's distance [40, 41]. As an overall measure of model fit, we computed McFadden's pseudo R^2. A McFadden's pseudo R^2 score in the range between 0.2 and 0.4 indicates an excellent fit [42]. We used R 4.0.3 statistical software to carry out all statistical analyses [43].

3. RESULTS

The distribution of PAPL scores was slightly left-skewed. The mean and median scores were approximately 72 and 75, respectively, with a standard deviation of 14.6. There were 227 students (39%) who obtained a score between 80 and 100. The highest density was between 60 and 80, with 255 students (44%) in that range.

Table 3.1 summarizes the Calculus I data for student preparedness and student success broken down by enrollment and demographic information. Of the 583 students, 338 (58%) were successful in the Calculus I course. Of students with PAPL score ≥ 75, 226 (75%) completed the course successfully. However, the success rate was low for students with PAPL score < 75 (40%).

Table 3.1: Summary of Student Preparedness & Outcomes in Calculus I by Enrollment & Demographic Factors.

		Student Academic Preparedness & Student Course Outcomes			
Category	Category Levels	PAPL Test Score ≥ 75		PAPL Test Score < 75	
		Success Or True Positive Rate (%)	Total (N)	Success Or False Negative Rate (%)	Total (N)
Course	In-person	74	262	38	243
Delivery	Online	85	39	49	39
Primary	Bachelor	75	271	38	250
Degree	Non-deg/Assoc/Cer	77	30	47	32
Enrollment	Full-Time	76	252	43	223
Status	Part-Time	69	49	29	59
Dual	Yes	70	10	25	8
Enrollment	No	75	291	40	274
STEM	Yes	75	228	39	204
	No	74	73	41	78
Sex	Male	75	181	36	170
	Female	76	120	46	112
Race	White	81	179	43	165
	Non-white	65	97	33	89
	Undisclosed	72	25	43	28
Ethnicity	Hispanic	71	21	31	23

	Non-Hispanic	75	280	41	259
Age	Below 20	77	203	41	160
	20-24	62	60	38	84
	Above 24	84	38	39	38
First-gen	Yes	70	101	35	101
Status	No	78	200	42	181
Low-	Yes	82	90	34	87
income	No	72	211	42	195
Total (N = 583)		75	301	40	282

Most of the students (87%) took the in-person version of Calculus I. The success rate for online students was higher (67%) than in-person students (57%). Of the total, approximately 89% were bachelor's degree seekers. At UAF, an undergraduate student is a full-time student if they are registered for at least 12 credit hours in a semester (i.e., Fall or Spring) [44]. However, for graduate students, this requirement is nine credit hours. Of the 301 well-prepared students, 84% enrolled as full-time students. Of the 282 less-well-prepared students, 80% enrolled as full-time students. Approximately 60% of full-time and 47% of part-time students were academically successful in Calculus I.

Along with mainstream Calculus I students, we also included dual enrollment students in our study. In Calculus I, the participation of dual enrollment students was very low (3%). Among them, 67% took the course through UAF's eCampus, 56% were well-prepared, and 50% were successful in the course.
Of the 351 male students, 52% were well-prepared, and 56% succeeded in Calculus I. Of the female students, 52% were well-prepared, and 61% succeeded in Calculus I. Of the 432 STEM intending students, male students (63%) outnumbered female students (37%). The success rate was higher for STEM intending female students (62%) than the STEM intending male students (56%). Students who took Calculus I were on an average 20.72 years old with a standard deviation of 5.25. Of the total, 62% of students were below 20 years old.

In our study, the racial composition of White: non-White: undisclosed race was 59%: 32%: 9% and 8% were Hispanic students. Based on student enrollment information in Calculus I, most students belonged to the White group. This order was unchanged for student preparedness; 52% of White, 52% of non-White, and 47% of undisclosed race students were well-prepared for Calculus I. Finally, the student success rates were 63% for White, 49% for non-White, and 57% for undisclosed race.

Of the Hispanic students, 48% came with sufficient prior knowledge for Calculus I, and 50% succeeded. These rates were 52% and 59% for non-Hispanic students. The participation of first-gen students was low (35%) in Calculus I compared to UAF's average (50%). Of the 202 first-gen students, 50% were ready to learn college-level Calculus I, and 52% succeeded in the course. Among non-first-gen students, 52% were well-prepared, and 61% succeeded in Calculus I. Approximately one-third (30%) of the students came from low-income families. The student success rates were 59% and 58% for low-income and non-low-income students, respectively.

Recall that we had more than 670 observations in the initial dataset. Among them, twenty-six students obtained a score of zero in the PAPL test. We removed those records from our data analysis. However, among those twenty-six students, only 1 (4%) student succeeded, 10 (38%) enrolled in the online version of the course, 6 (23%) were Hispanic, and 7 (27%) came from low-income families.

Table 3.2 shows a semester-to-semester comparison of Calculus I data in terms of mean PAPL test score with the standard deviation, correlation between PAPL test score and Calculus I grade, percentage of well-prepared and successful students, accuracy rate of 75 cut-score, false positive and false negative rates.

Table 3.2: Semester-to-Semester Comparison of Student Preparedness and Course Outcomes in Calculus I.

Semester	PAPL Test Score Mean(SD)	Correlation with Calculus I Grade	Greater or Equal of 75 cut-score (%)	Success Rate (%)	Accuracy Rate (%)	False Positive Rate (%)	False Negative Rate (%)
Fall 16(N=130)[a]	74.68(12.53)	0.43*	59.23	59.23	69.23	25.97	37.74
Fall 17(N=126)	72.58(14.32)	0.50*	47.62	59.52	64.29	25.00	45.45
Spring 18(N=86)	72.91(14.51)	0.68*	54.65	54.65	72.09	25.53	30.77
Fall 18(N=107)	71.18(15.52)	0.49*	52.34	58.88	67.29	25.00	41.18
Spring 19(N=59)	69.11(15.72)	0.57*	45.76	49.15	69.49	29.63	31.25
Spring 20(N=75)	70.77(15.90)	0.54*	45.33	62.67	66.67	17.65	46.34
Total(N=583)	72.26(14.60)	0.52*	51.63	57.98	67.92	24.92	39.72

a = Uncoordinated Calculus I

Significance Code: '*' (P < 0.0001)

We found that enrollment was higher in the Fall semesters (on average 121 students) than in the Spring semesters (on average 74 students). The highest and lowest enrollments in the Calculus I course were in Fall 2016 (N = 130) and Spring 2019 (N = 59). The mean PAPL test score was highest for Fall 2016 (74.68) and lowest for Spring 2019 (69.11). Calculus I's success rate was highest for Spring 2020 (62.67%) and lowest for Spring 2019 (49.15%).

We found a positive linear association between student preparedness (e.g., PAPL test scores) and course outcomes (e.g., Calculus I grade points) ($r = 0.52$, $P < 0.0001$, Table 3.2). The overall accuracy rate was found to be 67.92%. The overall false positive rate was 24.92%, which means that for well-prepared students, 24.92% did not complete Calculus I successfully. The overall false negative rate was 39.72%, which means 39.72% of students succeeded in Calculus I even though they did not achieve the cut-score in the PAPL test.

We examined whether, at UAF, student preparedness for Calculus I declined over the semesters in the study. We noticed a decrease in the mean PAPL score in Spring 19 (69.11) and overall a rough downward trend in the mean PAPL score from Fall 2016 to Spring 2019 (Figure A.1). We combined all PAPL scores and applied a simple linear regression model to find any possible linear association between the PAPL scores and semesters. The estimated slope of -0.4757 was significant ($P < 0.05$) indicating that, on average, PAPL scores are estimated to decrease by a little less than a half point per semester. Model diagnostics did not indicate any violations of model assumptions.

The results of all one-tailed Welch's t-tests are presented in Table 3.3. A significant difference was found between mean PAPL scores for successful and unsuccessful students ($P < 0.0001$). The estimated mean score for successful students was 77.72, approximately 13 points higher than unsuccessful students. Marginally significant differences were found between mean PAPL scores for students in the fall vs. spring ($P \approx 0.08358$), and bachelor vs. non-bachelor seeking students ($P = 0.0675$). All other comparison were not significant.

Table 3.3: Student Preparedness: Results of Welch's t-test (one-tailed). The first column describes the alternative hypothesis of a t-test. The second, third and fourth columns report the t-statistic, degrees of freedom, and p-value with a significance code respectively.

Alternative Hypothesis	T-statistic	DF	P-value
Students who took Calculus I in the Fall semesters had a higher mean score on the PAPL test.	1.3837	432.84	0.08358 '.'
Successful students had a higher mean score on the PAPL test compared to unsuccessful students.	11.371	445.91	<2.20e-16 '***'
In-person students had a higher mean score on the PAPL test compared to online students.	0.3382	97.671	0.368
Degree-seeking bachelor students had a higher mean score on the PAPL test.	1.511	75.018	0.0675 '.'
Dual enrollment students had a higher mean score on the PAPL test compared to non-dual enrollment students.	0.3148	18.129	0.3783

STEM intending students had a higher mean score on the PAPL test compared to non-STEM students.	1.0671	260.61	0.1434
Female students had a higher mean score on the PAPL test compared to male students.	0.4784	520.37	0.6837
STEM-female students had a higher mean score on the PAPL test compared to STEM-male students.	0.3141	346.16	0.3768
Non-Hispanic students had a higher mean score on the PAPL test compared to Hispanic students.	1.0095	48.676	0.1589
Non-first-gen students had a higher mean score on the PAPL test compared to first-gen students.	0.6513	377.01	0.2576
Non-low-income students had a higher mean score on the PAPL test compared to students with low-income status.	0.6766	290.23	0.2496
Significance Codes	'***' P < 0.001, '**' P < 0.01, '*' P < 0.05, '.' P < 0.1		

We examined student preparedness by categorizing students into three age groups, i.e., aged below 20, 20-24, and aged above 24. We noticed a difference in the level of preparation (ANOVA test, $P < 0.01$). On further investigation, we found that students below 20 had higher preparation levels than those aged 20-24 (Tukey's method, $P < 0.001$). Student level of preparation for Calculus was consistent across all three types of races (ANOVA test, $P > 0.5$).

Table 3.4 provides the results of three logistic regression models. For each model we summarized the odds ratio and associated p-value for each factor. The predictor PAPL test score was significant in all three models ($P < 0.0001$). Among enrollment factors, course delivery method, primary degree, and credit hour enrollment were significant in Model II and Model III. Among demographic factors, race was significant in Model III. These significant factors had an impact on course outcomes in Calculus I. The McFadden Pseudo R^2 was best for Model III ($R^2 = 0.22$). Therefore, we interpret the coefficients of Model III for each significant predictor.

Note that we also added a random factor, semester, to the logistic regression model (Model III). We found approximately a zero variance. Moreover, the likelihood ratio test was insignificant for the mixed-effects logistic regression. Therefore, we interpret the results of semester independent logistic regression.

Table 3.4: Student Success: Results of Logistic Regression Models.

	Model I		Model II		Model III	
Regression Coefficients	Odds Ratio	P-value	Odds Ratio	P-value	Odds Ratio	P-value
PAPL Test Score	1.0760	<0.0001	1.0811	<0.0001	1.0843	<0.0001
Online[a]			2.797	<0.01	3.0023	<0.01
Non-deg/Assoc/Cer[a]			5.3598	<0.001	5.1629	<0.001
Credit Hour[a]			1.2194	<0.0001	1.2144	<0.0001
Dual[a]			0.3451	0.1011	0.468	0.2827
STEM[a]			1.0761	0.7805	1.0647	0.8733
Male[b]					0.7565	0.4904
Age[b]					0.9891	0.5981
Undisclosed Race[b]					2.3136	<0.05
White[b]					2.3515	<0.001
Non-Hispanic[b]					0.6432	0.2797
Non-First Gen[b]					1.3912	0.1223
Low income[b]					1.3488	0.2004
STEM : Male[c]					1.0815	0.8673
McFadden Pseudo R^2	0.15		0.2		0.22	

[a] Enrollment factors.

[b] Demographic factors.

[c] Interaction term between STEM and Sex.

Based on the results of Model III, the odds ratio was 1.0843 for the PAPL test, which means the odds of success in Calculus I increase by a factor of 1.0843, or 8.43%, with each additional point score on the PAPL test, when all other factors were fixed ($P < 0.0001$). The associated 95% Confidence Interval (CI) was 1.07 to 1.1.

We found that the odds of success were three times greater for online students in Calculus I compared to in-person students for fixed values of the other variables (95% CI: 1.48 – 6.08, $P < 0.01$). The odds of success were 5.16 higher for non-bachelor seeking students compared to bachelor's degree seeking students, when all other factors were fixed (95% CI: 1.95 – 13.68, $P < 0.001$).

In the logistic regression model, we considered enrolled credit hours as a numerical variable. We found that an additional credit hour enrollment increased the odds of success in Calculus I by a factor of 1.21 for fixed values of the other variables (95% CI: 1.12 – 1.32, $P < 0.0001$). At UAF, White students were found most successful in Calculus I. For race, the odds of success were 2.35 times higher for White students (95% CI: 1.46 – 3.8, $P < 0.001$), and the odds of success were 2.31 times higher for students with undisclosed race (95% CI: 1.07 – 4.99, $P < 0.05$) in Calculus I compared to non-White students, when all other factors were fixed.

We failed to detect any evidence of an achievement gap in Calculus I between dual and non-dual enrollment students ($P > 0.2$) as well as between STEM and non-STEM students ($P > 0.8$). There was no significant gender gap in the course outcomes ($P > 0.4$) in Calculus I. The likelihood of success in Calculus I for STEM students did not differ significantly between males and females ($P > 0.8$). While analyzing student success, we included age as a numerical variable in the logistic regression. There was no significant evidence of a change in the odds of success based on age ($P > 0.5$). The likelihood of being successful in Calculus was not found to differ by ethnicity ($P > 0.2$) or first-gen status ($P > 0.1$). At UAF, Calculus I student income status did not affect their success ($P > 0.2$) in the course outcomes. More results can be found in the appendix section.

4. DISCUSSION

Applying to and entering a college or university is a significant accomplishment for high school graduates. First-year experience and performance can fuel achievements in the succeeding years. Students, mostly from STEM disciplines and a good portion of non-STEM students, take at least one math course in their first year of college study [3]. The DMS at UAF wants students to succeed in their first-semester math courses, particularly in Calculus I.

It can be assumed that well-prepared students are most likely to succeed in Calculus I. Approximately 67% of students who succeeded in Calculus I were well-prepared for the course. Looking across the semester-to-semester comparison of Calculus I data, we noticed that the Spring 2019 students with lowest mean score on the PAPL test (69.11) completed the course with lowest success rate (49.15%).

We see that the PAPL test taken at the beginning of the semester is a useful tool for identifying students who are likely to be successful in Calculus I, and students who are likely to struggle with the course content. This is true even though students placed into Calculus I through one of several traditional paths: coursework, high school math grades, ACT/SAT math scores or unproctored ALEKS scores. Our study found that successful students in Calculus I scored significantly higher on the PAPL test than unsuccessful students. The odds ratio for the PAPL score was estimated to be approximately 1.0843. This implies, for example, that for two students with the same values for academic, enrollment, and demographic variables, a student scoring 1 point higher has 8.43% better odds of success in Calculus I. For a 5-point difference in scores, the odds are approximately 50% higher, and 125% higher for a 10-point difference.

Enrollment factors also play an important role in student success and may be useful for advising. Although there was no significant difference in preparation, the odds of success for online students were greater than in-person students. As noted earlier, 42% of a student's grade in UAF, online Calculus I course was based on unproctored assessment, compared to 12% in the in-person setting. This disparity could be a reason for the higher odds of success for online students. Degree-seeking students were marginally more prepared than non-degree-seeking students. However, given the same PAPL score and values for other variables, their odds of success were lower. We notice that less than 10% of degree-seeking and approximately 47% of non-degree-seeking students took Calculus I through distance learning. The higher odds of success for online students are also reflected in the odds of success for non-degree-seeking Calculus I students. Number of credit hours is also a significant predictor of success. Full-time students spend more time in class during a semester than part-time students. Our study found that the odds of success in Calculus I increase with the number of credits in the corresponding semester. Interestingly, no differences were found in preparation or odds of success for STEM or non-STEM intending students.

Demographic factors were also found to be important in student success in Calculus I. While not used for advising, these differences can indicate areas in need of improvement in terms of student outreach. The "Gender Gap" is one of the most heated discussions in math education. Cultural stereotypes, e.g., male superiority, play a significant role in lowering self-efficacy and elevating anxieties in math and science for female students [45, 46]. No evidence was found in our study to support the stereotypes about male dominance in Calculus I at UAF. Further, we examined student preparedness and course outcomes for STEM students by sex. Even though participation of male STEM students in Calculus I was higher, we found no preparation and achievement gap in STEM students by sex.

This Paper provides insight into student preparedness and success in Calculus I between White and non-White students and between Hispanic and non-Hispanic students at UAF. We see that in terms of enrollment, preparedness, and success in Calculus I, White students comprise a significant majority and they succeed at higher rates than non-White students even when controlling for PAPL score. The high percentage of White students in Calculus I combined with their higher passing rates contribute to a decrease in the racial diversity in STEM disciplines at UAF.

Our study failed to find any evidence to support inconsistency in preparedness among three racial groups. Nevertheless, non-White students were far behind in success than the White and students of undisclosed race. In terms of ethnicity, student preparedness and course outcomes were similar between Hispanic and non-Hispanic students. Although often discussed in the literature, our study found no significant differences in preparation or odds of success for first-gen compared to non-first-gen students, or low-income vs non-low-income students. In postsecondary education, first-gen students are considered as "at-risk" in academic persistence, retention, and degree attainment [47, 48].

Like all public institutions of higher education, UAF has a strict nondiscrimination policy. Every syllabus for every course must explicitly state that discrimination on the basis of race is unacceptable. However, the achievement gap in Calculus I by racial composition is evident and cannot be avoided. UAF's Strategic Planning Goals, 2019-2025, has defined the importance of embracing and growing a culture of respect, diversity, inclusion, and caring that aims to establish equity and inclusion in educational opportunities at UAF [49]. UAF plans to increase STEM enrollment, retention, and graduation. In July 2017, UAF received a $1.7 million National Science Foundation (NSF) grant and another $1.3 million federal grant on October 2020 to foster STEM education at UAF [50, 51]. Moreover, the Student Success Initiatives (SSI) at UAF support students through academic and careers guidance, mentorship, leadership and professional development, co-curricular and community-based engagement. A supportive learning environment along ability to learn independently and understand the fundamental concepts of Calculus I are necessary to be successful in the course.

5. CONCLUSIONS AND RECOMMENDATIONS

At UAF, students can take the ALEKS PPL test free of cost. The test covers material from basic math through precalculus. Students can retake the test up to four times within a year from the initial test date [52]. Students have access to the ALEKS Prep and Learning Module to review and learn materials and prepare themselves for better course outcomes.

We hypothesized that the DMS could use the PAPL test as an adaptive tool to evaluate student preparedness for college-level Calculus I. Students have access to the ALEKS Prep and Learning Module for self-study.

Students could use these materials to fill their deficiency in precalculus content knowledge and prepare themselves for Calculus I. We found that PAPL test scores play an essential role in measuring student preparedness and could indicate student success in Calculus I. Our study found a positive correlation between the level of preparation in terms of the PAPL test scores and final course outcomes in Calculus I. The chance of getting a final grade of C- or higher in Calculus I generally increased with an increment in the PAPL test score. We found that each additional score on the PAPL test was associated with an increase in the odds of success in Calculus I by 8.43%, when all other factors were fixed ($P < 0.0001$).

However, the most striking fact was the high DFW rate (42%), which exceeded the national average DFW rate in Calculus I by 15% [53]. DFW students exhibited a lack of proficiency in precalculus content knowledge. Even though 30% of DFW students scored ≥ 75 on the PAPL test, their average score (64.72) on the test was 13 points lower than the students who had been successful in Calculus I ($P < 0.0001$). A deficient background in precalculus likely prevented students from succeeding.

Approximately 52% of Calculus I students were well-prepared for the course and 75% succeeded in the course [Figure A.3]. The authors believe that the state of Alaska's high school math education policy may impact student preparedness for college-level math courses, particularly in Calculus I. The state high school math standards recommend its students learn specific math topics to prepare themselves for advanced classes, i.e., calculus, advanced statistics, or discrete math. However, it's not a requirement for high school students [54].

Calculus I students benefitted by taking the PAPL test under a proctored condition. Although 48% students scored below 75 on the PAPL test, we noticed that approximately 40% of the less-well-prepared students succeeded in the course [Figure A.3]. Therefore, the process of grouping out and placing students for precalculus courses restricts student enrollment in Calculus I that may discourage them and eventually may result in students never passing the course they otherwise might have. Therefore, the DMS must take structural and instructional improvements to reduce Calculus I's overall achievement gap.

Each semester the DMS at UAF assigns enough Teaching Assistants (TAs) to conduct student advising and mentoring programs. TAs support students through a mathematics lab, computer lab, one-on-one in-person and online tutoring, group tutoring, homework help, recitation sessions for lower and upper-level math and stat courses. In addition, outside of class, instructors hold office hours to support Calculus I students. To train and prepare TAs, DMS offers a graduate level teaching seminar. TAs must take the seminar course to provide the best support to students who seek academic help. The MAA study identified five types of support available and helpful for Calculus I students: tutoring center, office hours, college or university-wide support services, special course options, and transfer assistant [3].

As noted earlier, student success should be a multi-dimensional study. In this study, our primary interest was to examine the significance of the PAPL test score as a measure of preparedness for college-level Calculus I while controlling for student enrollment status and demographic information. Further study may include institutional (i.e., resource allocation, student support services, summer bridge programs), instructional (i.e., teaching approaches, use of technology), environmental (i.e., class size, class time, peers), and personal (i.e., ability, motivation, self-regulatory strategies) factors on a broader scale. Studies based on K-12 levels suggest that student-instructor rapport is an important indicator of student success [55, 56]. Therefore, instructors' characteristics, i.e., education level, years of experience, professional status, and their effects on student success, may be interesting to include in the study.

It is more likely that a proctored test reflects student actual content knowledge because it reduces the incentive to cheat. This study did not include unproctored ALEKS PPL scores. A potential topic of future research is to investigate student preparedness and student success in Calculus I while considering unproctored ALEKS PPL test scores and compare the findings with the proctored one. It is also vital to study student attitudes towards such implementation. Their comfort with and motivation for taking a proctored online test could be measured by their preparation time for the test, usage of available resources for self-study, level of efforts at each subsection, number of previous attempts until the proctored test.

Even though Calculus I is not required for most non-STEM disciplines, the participation and performance of these students were remarkable. Of the total, 26% of students came from non-STEM disciplines. Among them 48% were well-prepared and 57% succeeded in Calculus I. Therefore, implementing the PAPL test as an adaptive tool and a course requirement may affect non-STEM student motivation in taking Calculus I because they may not appear in subsequent courses. Moreover, in our initial dataset, 10% of students were repeating. A survey-based study on non-STEM Calculus I students and repeating students while controlling their career trajectories may be an exciting topic for further investigation.

The effectiveness of implementing the PAPL test as an adaptive tool and Calculus I course requirement can be monitored by further investigation of student retention, preparedness, and success in subsequent courses, i.e., Calculus II and Calculus III.

The student-instructor gender gap is one of the much-heated discussions and it has an impact in student engagement and student achievement. Most of the recent debates in gender interactions are centered around the controversial claim that boys are getting more positive feedback in class discussions [57]. The two possible effects often discussed in explaining the demographic interactions between students and instructors, are “role-model effect”, i.e., when demographically similar teacher raises student academic motivations, and aspirations, and “stereotype threat”, i.e., when demographically dissimilarity happens between students and instructors that could retards student academic expectations and outcomes [57, 58, 59]. Therefore, we recommend measuring the significance of instructors’ gender and their professional positions in analyzing student success in Calculus I.

This study provides insights into the Calculus I at UAF that will help DMS leadership to identify, plan, implement and assess program improvements. Our study does not suggest placing students for precalculus based on the PAPL test score. Taking a precalculus course may not be the most crucial factor in determining course outcomes in Calculus I. Many students may find genuine interest in learning Calculus I for the first time that may play a motivational factor in performing better in the course. Moreover, a 2014 study reported that taking college precalculus does not help students substantially to achieve higher college calculus grades [19]. Instead, we recommend implementing the PAPL test as an adaptive learning tool and a requirement for Calculus I at UAF and establishing a student-centered standard to address the student knowledge gap in precalculus.

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APPENDIX

Table A.1: A Contingency Table of Student Preparedness and course Outcomes.

Course Outcome / Preparedness	Successful (A grade of C- or higher)	Unsuccessful (DFW)
Well-prepared Students (PAPL Test Scores ≥ 75)	True Positive (TP)	False Positive (FP)
Less-well-prepared Students (PAPL Test Scores < 75)	False Negative (FN)	True Negative (TN)

TP = No. of well-prepared students who succeeded in Calculus I.

FP = No. of well-prepared students who failed in Calculus I.

FN = No. of less-well-prepared students who succeeded in Calculus I.

TN = No. of less-well-prepared students who failed in Calculus I.

Accuracy Rate = Proportion of students correctly categorized by 75% cut-score = $\frac{TP + TN}{TP + FP + FN + TN} * 100$.

True Positive Rate = Proportion of well-prepared students who passed in Calculus I = $\frac{TP}{TP + FP} * 100$.

False Positive Rate = Proportion of well-prepared students who failed in Calculus I = $\frac{FP}{TP + FP} * 100$.

False Negative Rate = Proportion of less-well-prepared students who succeeded in Calculus I = $\frac{FN}{FN + TN} * 100$.

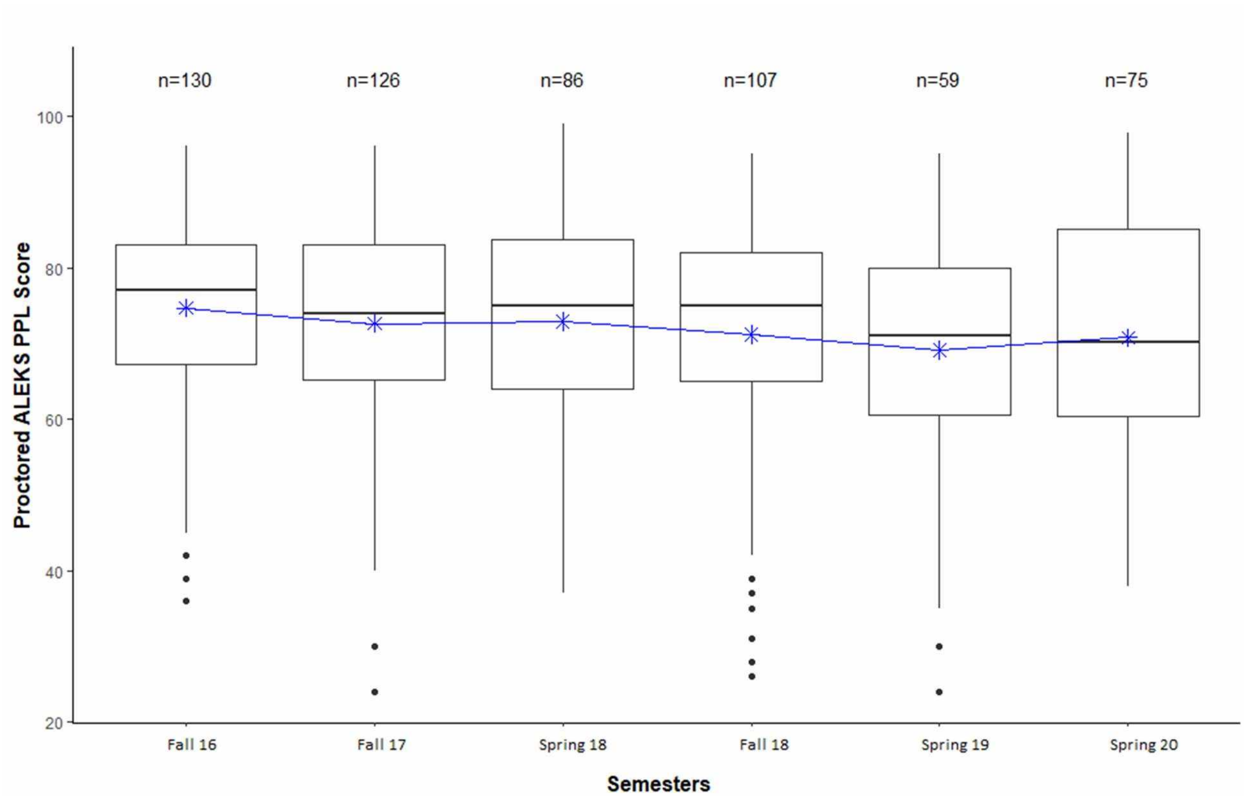

Figure A.1: Distribution of PAPL Test Scores by Semesters. Asterisk mark denotes the mean value of the PAPL test scores in respective semesters. We see a consistency in the level of preparation for Calculus I over the semesters. However, the mean PAPL score was lowest for Spring 19. The top row contains the enrollments in associated semesters, and the dots are outliers.

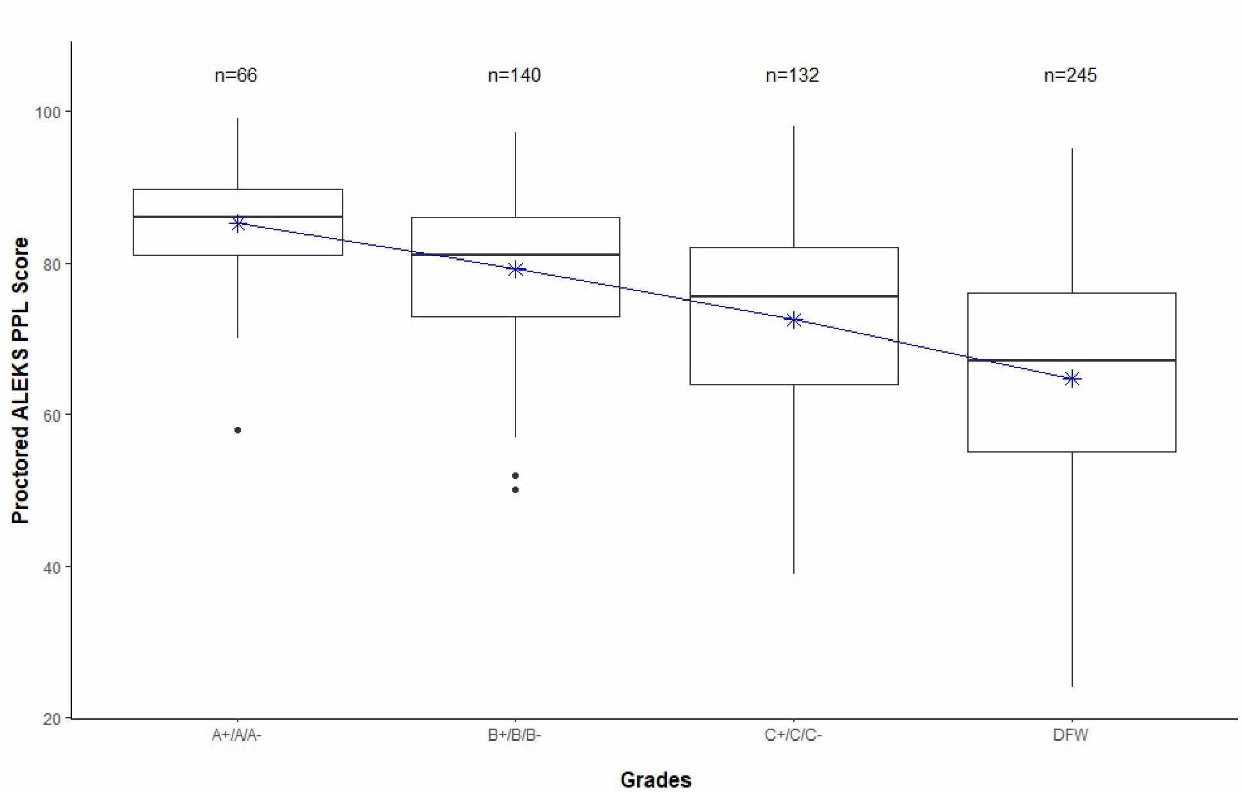

Figure A.2: Distribution of PAPL Test Scores by Student Grades. Asterisk mark denotes the mean value of the PAPL test scores for associated grades. We see a positive association between student level of preparation and their obtained grades in Calculus I. Students with a higher level of preparation completed the course with a higher grade. Most of the least prepared students were unsuccessful in the course.

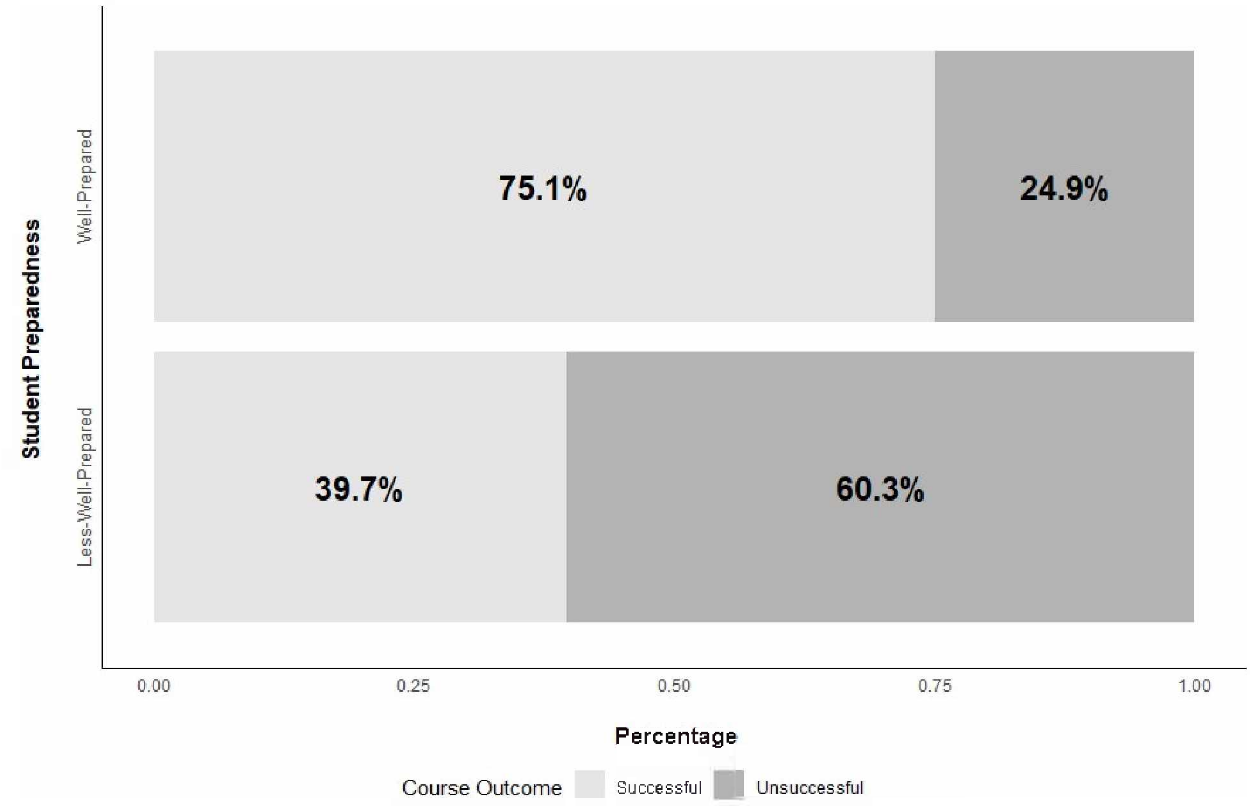

Figure A.3: 75% of well-prepared students succeeded in Calculus I, the true-positive rate. Approximately 40% of less-well-prepared students succeeded in the course, the false-negative rate. Student preparation had a significant impact on student success of Calculus I.

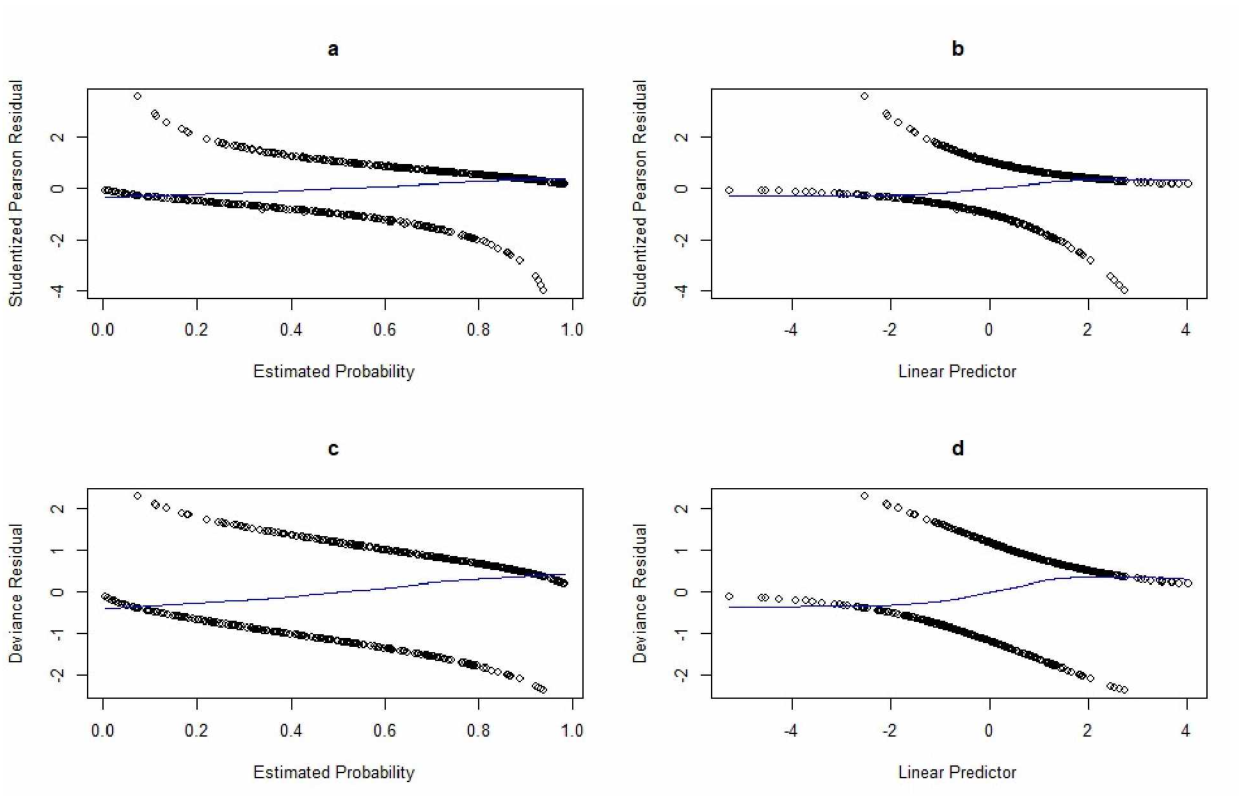

Figure A.4: Logistic Regression (Model III) Diagnostics: Residual Plots with Lowess Smooth. (a) Studentized Pearson Residual vs. Estimated Probability, (b) Studentized Pearson Residual vs. Linear Predictor, (c) Deviance Residual vs. Estimated Probability, (d) Deviance Residual vs. Linear Predictor. Residual plots contain roughly horizontal with zero intercept smoothed lines. Hence, the fitted model was adequate [40, 41]. Moreover, McFadden Pseudo R^2 was 0.22, which means fitted logistic regression (Model III) was adequate and excellent [42].

Table A.2: Understanding the Insights of, Who Takes, and How Students Perform in Calculus I: A Comparison between UAF Calculus I Study and MAA National Calculus I Study [3].

Characteristics of Calculus I Student	UAF Calculus I Study	MAA National Calculus I Study
Full-Time	81%	92%
Male	60%	57%
White	59%	76%
Black	2.4%	7%
Asian	3%	12%
Hispanic	8%	11%
Mean Age (SD)	20.72 (5.25)	19.7 (3.5)
Non-first-gen Status or Parents Education	Non-first-gen – 65%	Father Completed College – 56% Mother Completed College – 53%
Among Successful Students	A (20%) B (41%) C (39%)	A (40%) B (40%) C (20%)
DFW	42%	27% [53]

At UAF, Calculus I students were predominantly full-time (81%), bachelor's degree seekers (89%), male (60%), White (59%), non-Hispanic (92%). Looking across the results of Calculus I students who had been successful, roughly 20% getting an A, 41% a B, and 39% a C, whereas in the MAA's national study, these percentages were 40%, 40%, and 20%, for grades A, B, and C respectively [3].