Calculus Redesign to Include Recitation Activities and its Effect on Student Success

Jacob Dasinger, Madhuri S. Mulekar, and Audi Byrne

University of South Alabama

Calculus I has historically been one of the most difficult courses to pass for college students. Often referred to as a "gateway" course for Science, Technology, Engineering, and Mathematics (STEM) majors, Calculus I is frequently a prerequisite to core courses in STEM education such as biological sciences, engineering, and higher-level mathematics. As more STEM occupations are being created versus non-STEM occupations (Noonan, 2017) and more students aspire to major in STEM fields, universities are under an ever-increasing pressure to increase success rates in Calculus I without lowering standards. The goal of this paper is to provide verification of a strategy combining established best practices that would improve overall course grades in a Calculus I course, be relatively easy to have faculty buy into its implementation, increase graduate student enrollment, and save departments and universities money.

Literature Review

In order to improve outcomes in Calculus I, several universities have modified the format in which Calculus I is taught. These modifications include intervention methods such as 1) developing alternate courses to bridge necessary deficiencies in at-risk students (bridge courses), 2) reformatting the structure of the course to increase contact hours, the use of Teaching Assistants, or alternative teaching methods such as Team-Based learning (course restructure), 3) tutoring and other sources of help (Supplemental Instruction) and 4) more uniformity in sections with common assessments such as homeworks and tests (course coordination). In our Calculus I redesign, we combined elements of course restructure, supplemental instruction and course coordination.

Course Restructure

Koch and Herren (2006) describe an intervention method used at the University of Michigan to help target at-risk students in Calculus I and provide a way for these students to increase their chance to succeed by offering alternate paths to the next course. Similarly, Hensel, Sigler, and Lowery (2008) instituted a calculus readiness course during the second half of the semester to target struggling engineering majors at West Virginia University. In another effort to increase contact hours, Subramanian, Cates, and Gutarts (2009) describe an intervention tool to improve success rates in calculus courses at California State University, Los Angeles. The major changes included moving to a 4-day a week schedule and implementing mandated workshops where students would work problems in small groups, with a teaching assistant, most often a graduate student, available to provide guidance if needed.

Supplemental Instruction

In addition to restructuring courses to offer more time to be prepared for Calculus courses, additional time spent on task can be added to the course itself in the form of supplemental instruction. In 2011, California State Northridge developed a new Calculus I course to help increase student success (Horn & Shubin, 2013). This new course contained a supplemental one-hour meeting where students would complete group work assignments, included online homework across all sections that provided immediate feedback, and added the use of free online math tutoring. Watt, Feldhaus, Sorge, Fore, Gavrin, and Marrs (2014) describe the implementation of three different types of recitation sessions at Indiana University - Purdue University Indianapolis to first-semester, large enrollment (≥ 50 students), calculus sections in an attempt to improve calculus course grades. These recitations increased success rates in the targeted courses.

Course Coordintation

Increasing preparation and adding additional hours to Calculus can be successful interventions, but they may be more effective when the method of teaching also changes. In 2012, instructors at Iowa State University implemented team-based learning (TBL), a form of active learning done in small groups, in order to increase class attendance and overall course grades. After its inception, the class participation increased from 60% to 85% - 90%, and TBL sections scored higher, on average, on a departmental midterm and final exams, and on an overall calculus knowledge assessment (Brocklin, 2017).

In 2013, Montana State created a new program to provide enough tutors, training, and support to help ensure mathematics students could be successful in all their courses. By instituting concepts such as common lecture guides for instructors, online homework, early identification of struggling students, and assistance to those students who wanted it, Montana State was able to increase their success rate in Calculus I to 77 percent, up from 57 percent (Becker, 2017). Similarly, Bullock, Callahan, and Shadle (2015) transformed the first-semester calculus course at Boise State University by agreeing on common homework assignments and having lecture sessions mainly composed of solving problems and small group assignments, resulting in a higher pass rate.

In course redesign, a vast array of different strategies have been used to increase success rates in university calculus courses. However, depending on the availability of resources and support, some changes may be more daunting than others for a department looking to improve outcomes in their mathematics courses. For example, getting all faculty to teach using the same pedagogy or implement the same intervention tools can seem like a tall order. With state budgets decreasing across the country, funds for a state-of-the-art tutoring lab may not be feasible for some institutions. This study aimed to create a strategy that would increase success rates, be easily implemented at almost any university, and would save universities resources.

Background

The University of South Alabama is a mid-sized university located in Mobile, Alabama, enrolling approximately 16,000 undergraduate students per year. The Department of Mathematics and Statistics is one of the largest departments on campus, employing 41 full-time faculty members. The department offers an undergraduate degree in Mathematics and Statistics, and a Masters (MS) degree in Mathematics. Since the department does not offer a Ph.D. program, students enrolled in MS are not eligible to be instructors of record as per the accreditation rules. Calculus I is a 4-credit hour course that is the first one of 3-course calculus sequence offered by the department.

Placement into Calculus I is achieved by either having an ACT Math score of 27 or above, SAT Math score of 665 or above, sufficient score on the university's math placement test, or by earning a C or better in Pre-Calculus Trigonometry or Pre-Calculus Algebra and Trigonometry. Traditionally, the course was offered as (i) four 50-minute, (ii) three 70 minute, or (iii) two 100-minute class meetings every week for 15 weeks. Most students enrolling in

Calculus I are engineering, mathematics and statistics, secondary education – mathematics, and biomedical sciences majors. Although all sections cover the same curriculum, instructors have some freedom of deciding the order of topics, amount of time spent on different topics, types, and frequency of assessment, etc.

Redesign Pilot

The University of South Alabama historically had a high DFW grade rate in Calculus I. From Spring 2006 until Spring 2014, 47.6% of students enrolled in Calculus I earned either a grade of D, F, or WD (DFW), with the individual semesters DFW grade rates ranging from 33.9% to 58.6%. With a goal of improving students' knowledge and success rates, a redesign of this course was instituted in Fall 2014 and Spring 2015 semesters.

Similar to studies which employed supplemental instruction (Horn & Shubin, 2013), course coordination (Bullock, Callahan, and Shadle; 2015), and course restructuring (Hensel, Sigler, & Lowery, 2008; Subramanian, Cates, and Gutarts, 2009), the University of South Alabama Department of Mathematics and Statistics implemented a redesign pilot for its Calculus I course in the Fall 2014 and Spring 2015 semesters. With limited time and resources, a look at the time-tested view of more class time and engagement with the material was the focus. For these two semesters, the redesign of Calculus I course involved teaching this 4-credit hour course over 5 days a week in 50-minute sessions. Students were not charged extra tuition for this extra class time. Each instructor was assigned a graduate teaching assistant (GTA). Instructors lectured their class on Monday, Wednesday, and Friday, and the GTAs held recitation sessions on Tuesday and Thursday. All quizzes and exams were given during these recitation sessions to maximize lecture time. GTA's helped with grading quizzes and also held six office hours each week by providing free tutoring to students in the class. Traditional sections were offered with differing schedules (4 days a week, 3 days a week, or 2 days a week) as was the practice of many years in the department. Instructors taught all lectures and there were no GTAs assisting instructors of those sections in any way. Instructors decided the number of homework problems or quizzes to assign and how many to collect for a grade. However, all sections, traditional and redesign, were required to give three tests and a final exam.

All sections were taught by full-time faculty. No instructor was assigned to teach both traditional and redesigned sections in a given semester. Five instructors taught redesign sections and each one taught two redesign sections of Calculus I in a given semester. Instructors were

matched with GTAs, resulting in each GTA helping the same instructor with their two sections in that semester.

Data collected and analyzed for this redesign study included a pre-test and common exam questions. A pre-test was given during the first week of classes in each semester to students in all sections, traditional and redesign, to compare knowledge level of students going into sections with two different teaching methods. The pre-test consisted of 10 multiple-choice questions, each with five possible answer choices. The questions covered topics from Pre-Calculus Algebra and Trigonometry. Calculators were not allowed on the pre-test. The topics included were:

1. Find the slope-intercept form of a line given two points
2. Multiplying two complex numbers, and simplifying the product
3. Graphing an exponential function
4. Graphing a polynomial function
5. Find the domain and range of a radical function
6. Determining the amplitude and vertical shift of a sine function
7. Simplifying trigonometric expression
8. Finding the missing side of a triangle using Law of Sines
9. Converting a Cartesian point to Polar form
10. Solving trigonometric equation for all values $0 \leq t < 2\pi$

In addition to the pre-test, over the semester two common questions per exam were used in all sections to compare gains in students' knowledge. Remaining questions on those exams differed by instructor and were not used in the comparison. Although all sections were given three exams and a final exam, no common assessment was conducted with the final exam.

- Exam 1 contained two questions about limits (Fall 2014 and Spring 2015)
- Exam 2 had questions on derivatives (Fall 2014) and differentiation rules (Spring 2015)
- Exam 3 had questions on finding critical points and using L'Hopital's rule (Fall 2014 and Spring 2015)

Each question was graded on a scale of 0, 1, and 2 points. For analysis, the sum of scores on two questions from each of the three exams was computed for each student and will be referred to as Exam1, Exam2, and Exam3 respectively in the analysis. The possible total score range for each exam is 0 to 4. The average student grade on common assessment questions and

course success rates (earning an A, B, C) were used for comparison of outcomes for redesigned and traditional sections.

Results

The pre-test and exam scores were evaluated as well as the introduction of the GTAs. A two-sample *t*-test was used to compare the means of scores on the pre-test and common exam questions for the redesign and traditional sections. Table 1 shows the comparison of mean student scores on the pre-test and on common exam questions. Note that not all students took all exams resulting in data on differing numbers of students on different exams. One instructor failed to provide all requested information about the performance of students in his sections; therefore, the exam results in Table 1 do not include these students.

Table 1

Comparison between redesign and traditional sections of mean student scores on the pre-test and common exam questions

Group	**Score on**	**Fall 2014**				**Spring 2015**			
		N	**Mean**	**Std. Dev**	***p*-value**	**N**	**Mean**	**Std. Dev**	***p*-value**
Redesign	Pre-Test	170	39.71	21.69	0.3451	239	35.77	20.15	0.8065
Traditional	Pre-Test	119	42.10	20.83	(2-sided)	101	35.15	22.03	(2-sided)
Redesign	Exam1	80	3.30	0.86	<0.0001	163	2.48	1.23	0.0470
Traditional	Exam1	148	2.60	1.14	(1-sided)	99	2.20	1.46	(1-sided)
Redesign	Exam2	77	2.51	1.25	0.0009	162	3.10	1.21	< 0.0001
Traditional	Exam2	139	1.92	1.40	(1-sided)	95	1.93	1.52	(1-sided)
Redesign	Exam3	80	3.25	1.13	0.0006	160	3.43	0.92	0.0192
Traditional	Exam3	127	2.67	1.37	(1-sided)	86	3.08	0.98	(1-sided)

Table 2

Comparison of success rates in redesign and traditional sections of Calculus I

	Fall 2014	**Spring 2015**	**Overall**
Redesign	79 out of 115 **68.70%**	114 out of 167 **68.26%**	193 out of 282 **68.44%**
Traditional	93 out of 153 **60.78%**	60 out of 104 **57.69%**	153 out of 257 **59.53%**
p-value (1-sided)	0.091	0.039	0.016

Pre-test results from both semesters indicate no significant difference in the prior knowledge level of students in the redesign and traditional sections. For both groups, students entering Calculus I were considered comparable with respect to their pre-requisite mathematical knowledge as assessed by the pre-test (*t*-test, Fall 2014: $p = 0.3451$ and Spring 2015: $p = 0.8065$). In both semesters, in all three exams, students in redesign sections scored significantly higher on the average compared to students in traditional sections on the common assessment questions (*t*-test, $p < 0.05$ for each of three exams for both semesters).

A two-sample *z*-test was used to compare the success rate of redesign sections with that of traditional sections. In the Fall 2014 semester, the success rate (A, B, C) in redesign sections was higher by about 8% compared to the traditional sections. In the Spring 2015 semester, the success rate in redesign sections was higher by about 10% compared to the traditional sections (*z* -test, $p = 0.039$). Overall, about a 9% increase in the success rate of redesign over traditional sections was observed over the academic year (*z* -test, $p = 0.016$).

Based on the results of the pilot study, the Department of Mathematics and Statistics received three additional graduate teaching assistantships in the Fall 2015 semester and implemented the redesigned model in all sections of Calculus I. Table 3 shows mean scores on the pre-test and the success rates (A, B, C) of students from Fall 2015 until Spring 2017. The mean pre-test scores indicate that students in calculus I had a fairly similar level of pre-requisite knowledge over these four semesters. For all but one semester, the Department of Mathematics and Statistics has seen an increase in Calculus I success rates compared to the previous semester. A slight drop in success rate in Fall 2016 may have been due to a last-minute surge in enrollment

and new instructors in the program. In Spring 2017, a success rate of 74.07% observed in Calculus I was the highest ever in the past 10 years.

Table 3

Success Rates of Calculus I students since Fall 2015

Term	**N**	**Sections**	**Pre-Test Means**	**Success Rate (A,B,C)**
Fall 2015	314	8	36.11	67.52%
Spring 2016	324	10	37.47	69.75%
Fall 2016	488	13	35.77	65.57%
Spring 2017	324	11	31.00	74.07%

Graduate Teaching Assistants

The Graduate Teaching Assistants (GTAs) were both first- and second-year students in the Department of Mathematics and Statistics Master's program. GTAs were provided tuition-waivers and a stipend of $10,000 per academic year. As part of their duties, GTAs held recitation sessions on Tuesday and Thursday, where they would clarify topics covered in lecture, answer homework questions, and administer quizzes or exams. All GTAs met with their assigned instructors regularly to discuss and coordinate topics to be covered in recitation sessions, and to collaborate on best-practices for demonstration of Calculus I topics.

In addition to improved learning and success rates, teaching with GTAs is cost-effective and supports the teaching mission of the university. The involvement of GTAs in teaching has also helped prepare future mathematics teachers, a majority of the graduate students' career goal in this department. It was a great learning experience for GTAs to work closely with instructors on developing lesson plans, teaching, and assessment.

At the end of Fall 2015 and Fall 2016 semesters, students in all sections of Calculus I were asked to evaluate their graduate teaching assistants. Students were given a three-question survey asking them to rank the GTA's on a 5-point scale from 1) Strongly Agree, 2) Agree, 3) Neutral, 4) Disagree, and 5) Strongly Disagree, along with a free-form comment section. The questions were as follows:

1. The GTA was effective in answering questions and clarifying difficult concepts.

2. The GTA was effective in relating material from the instructor's lectures to his/her section discussions.
3. I would recommend calculus courses taught in this format (5 contact hours per week, with GTA) to other students needing to take calculus.

Table 4 shows descriptive statistics for Fall 2015 and Fall 2016 (note that lower mean indicates stronger agreement with statements). Overall, 71% to 89% of students supported redesign by responding as agree or strongly agree with the final question recommending the course format.

Table 4

Fall 2015/16 Descriptive Statistics for Graduate Teaching Assistants (GTA) Surveys. Number and percent responses are reported for each answer category and question.

	Fall 2015			Fall 2016		
	Q1	Q2	Q3	Q1	Q2	Q3
Mean score	1.21	1.28	1.52	1.46	1.50	1.55
Number of responses	159	159	159	202	202	201
1: Strongly agree	131 82.39%	122 76.73%	98 61.64%	130 64.37%	122 60.40%	119 58.91%
2: Agree	23 14.47%	32 20.13%	42 26.42%	57 28.22%	64 31.68%	61 30.20%
3: Neutral	4 2.52%	3 1.89%	16 10.06%	10 4.95%	12 5.94%	13 6.44%
4: Disagree	1 0.63%	2 1.26%	3 1.89%	5 2.48%	3 1.49%	7 3.47%
5: Strongly disagree	0 0.00%	0 0.00%	0 0.00%	0 0.00%	1 0.50%	1 0.50%

In addition to the data from the three survey questions, the results from the comment sections on the graduate teaching assistant surveys were analyzed. The majority of the comments were coded as positive comments. The most common positive response from students was how they enjoyed having the GTA explaining and working problems from the lecture class. Nevertheless, there were several negative responses by students that appeared with more regularity than other responses. One such response was dealing with classes meeting 5 days a week. While the results of this study showed increased class meetings improved overall course

grades and content knowledge, some students felt it was too much, and four days a week would be sufficient or having 3 days of recitation and 2 days of lecture would be preferred.

Another characteristic of the redesigned course that students felt negatively about was the number of quizzes administered in the course. With quizzes given almost every Tuesday and Thursday, some students expressed concern about "over-testing" and having quizzes count too much towards the overall grades. Also, with quizzes taking anywhere between 10 and 20 minutes, there is less time in lab sections to review homework and ask the GTA questions.

Conclusions

In Fall 2014, the University of South Alabama implemented a redesigned model of Calculus I using documented best practices with the intent of improving overall success rates. The main emphasis of the redesign was increasing contact hours from 4 to 5 per week, implementing the use of GTAs twice a week for recitation, and incorporating frequent assessments in the form of quizzes. After an initial pilot study of two semesters, results indicated a significant difference in both overall course grades and content knowledge in the redesign sections compared to the traditional sections. Since 2015, all sections of Calculus I have been implemented with the redesigned model and the high success rates of the pilot have been maintained (or increased, as in the Spring 2017 semester). A majority of students proceed to Calculus II upon successful completion of Calculus I. Historically, Calculus II also had low success rates, as low as 42% with a ten-year average of 55% before implementation of redesign in Calculus I. However, after implementation of redesign in Calculus I, the average success rate in Calculus II has jumped to 66% (Spring 2015 to Fall 2017), an eleven point increase.

Overall, the use of GTAs has had a positive effect on students and faculty. Some students may feel anxious about asking questions to instructors during class meetings for fear of being wrong in front of the instructor. Having recitation sessions allows students to feel more comfortable when asking GTAs questions. In addition, students get constant feedback from weekly quizzes, and faculty members can focus more on conveying the material in-class.

We continue to evaluate and fine-tune the implementation of the Calculus I redesign. For example, instructors have a choice as to whether they will give one or two quizzes per week, to address student concerns that there are too many quizzes. Future evaluation of the Calculus I redesign should follow and measure the progress and knowledge of redesign students in

subsequent courses. Further investigations can help identify reasons for the lack of success of students who need to take the course multiple times before successful completion.

In addition to these changes in Calculus I, the department is also looking into redesigning other courses. This experience confirms that students required to have more structured time engaging with the material can be more successful. As a result of this engagement, students have more time to become familiar with the material and more confidently transfer it to the next course.

References

Becker, M. (2017, June 6). A new formula for success. *The Montana State University Magazine: Mountains & Minds*. http://www.montana.edu/mountainsandminds/article.php?article=16941.

Brocklin, P. V. (2017, March 23). Math faculty examine numbers to improve student learning. *Inside Iowa State*. http://www.inside.iastate.edu/article/2017/03/23/math.

Bullock, D., Callahan, J., & Cullers, J. B. S. (2017). *Increasing STEM retention and post-requisite course success while closing the retention gap for women and underrepresented minority students*. Paper presented at the American Society of Engineering Education Conference.

Hensel, R. H., Sigler, J. R., & Lowery, A. (2008). *Breaking the cycle of calculus failure: Models of early math intervention to enhance engineering retention*. Paper presented at the American Society of Engineering Education Conference, Pittsburg, PA.

Horn, W. & Shubin, C. (2013) *Improved enrollment and pass rates in calculus*. http://www.csun.edu/~vcmth014/CSU_Aligning/m150A_article_4_2013.pdf.

Koch, D. & Herrin, G. D. (2006). *Intervention strategy for improving success rates in calculus.* Paper presented at the American Society of Engineering Education Conference.

Noonan, R. (2017). *STEM Jobs: 2017 update.* U.S. Department of Commerce, Economics and Statistics Administration, Office of the Chief Economist.

Subramanian, P. K., Cates, M., & Gutarts, B. (2009). Improving calculus success rates at California State University Los Angeles. *Mathematics and Computer Education*.

Watt, J. X., Feldhaus, C. R., Sorge, B. H., Fore, G. A., Gavrin, A. D., & Marrs, K. A. (2014). The effects of implementing recitation activities on success rates in a college calculus course. *Journal of the Scholarship of Teaching and Learning*, *14* (4), 1 – 17.