

Unclogging the Calculus Pipeline

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Abstract

At Missouri University of Science and Technology, less than 10% of students with a D or F in Calculus I at midterm finished the course with a grade of C or better in recent semesters. These students who find themselves in a nearly insurmountable hole at midterm are often the students who are least likely to seek out assistance, and they are often struggling with far more than just mathematics. In Fall 2015, we implemented a new half-semester course, Success for Calculus, to give these students a fresh start and the opportunity to reinforce their mathematical preparedness while also addressing many of their struggles with non-mathematical issues. We discuss how this course has evolved, its structure, and its impact on our students.

Unclogging the Calculus Pipeline

In 2013, the administration of Missouri University of Science and Technology (Missouri S&T) released a new strategic plan. One goal stated in the strategic plan was, as a campus, to “modify our conventional methods of teaching to accommodate current, new and advanced technology that will enhance student learning and increase faculty productivity.” While this sounds sufficiently general (as would befit a strategic planning document), the document rapidly became far more specific when it indicated that the desired outcome was to increase calculus success rates. This led us to begin a mandated, comprehensive review of our Calculus I, II, and III offerings.

Since enrollment in each of Calculus II, Calculus III, and Differential Equations requires a C or better in prerequisite coursework, we defined grades of A, B, and C to be successful and all other transcribed grades (D, F, WD, HR) to be unsuccessful. Although we began the redesign effort in Fall 2013, most of the initial data presented here runs through Spring 2015 because of a substantive change introduced as part of the redesign in Fall 2015.

Historic Success Rates Winter 2004 - Spring 2015		
Course Title	Total Enrollment	Success Rate
Calculus I	10155	68.35%
Calculus II	10008	79.51%
Calculus III	9342	74.04%

While none of these success rates were out of line with what we expected, the Calculus I success rate was enough lower than the Calculus II and III rates to merit further attention, particularly because of the impact of Calculus I on student progression into science and engineering coursework.

The first question we explored with the Calculus I cohort was whether students who experienced success in Calculus I were generally successful in their first attempt at Calculus II.

First Attempt in Calculus II after Success in Calculus I Winter 2004 - Spring 2015							
	Calc II - A	Calc II - B	Calc II - C	Calc II - D	Calc II - F	Calc II - WD	Calc II - HR
Calc I - A	75.25%	17.61%	4.81%	0.39%	0.78%	0.54%	0.62%
Calc I - B	30.77%	38.28%	21.25%	3.29%	2.10%	2.18%	2.13%
Calc I - C	5.77%	22.52%	36.84%	12.11%	9.53%	6.05%	7.18%

This detailed breakdown leads us to the following overall pass rates for successful Calculus I students in their first attempt in Calculus II.

First Attempt in Calculus II after Success in Calculus I Winter 2004 - Spring 2015	
Grade in Calc I	Calc II Pass Rate
A	97.67%
B	90.31%
C	65.13%

Thus, students who performed extremely well in Calculus I usually did well on their first attempt in Calculus II. It comes as no shock that students with only marginal preparation (as indicated by a C in Calculus I) found Calculus II to be more of a struggle.

Once we were convinced that Calculus I was adequately preparing students for success in Calculus II, we turned our focus to the students who were unsuccessful in Calculus I. Since many of our unsuccessful students in Calculus I attempt the course at least one additional time, we wanted to see how students who were unsuccessful on their first attempt performed on their second attempt in Calculus I.

Students Retaking Calculus I Winter 2004 - Spring 2015							
Second Attempt →	A	B	C	D	F	WD	HR
First Attempt ↓							
D	2.70%	27.36%	42.00%	17.53%	8.09%	1.93%	0.39%
F	0.62%	10.91%	24.90%	22.22%	32.92%	8.23%	0.20%
WD	1.27%	8.90%	28.81%	14.83%	30.09%	13.98%	2.12%
HR	1.23%	8.59%	34.36%	18.40%	24.54%	9.20%	3.68%

This detailed breakdown leads us to the following overall summary.

Students Retaking Calculus I Winter 2004 - Spring 2015	
First Attempt	Pass Rate on Second Attempt
D	72.06%
F	36.42%
WD	38.98%
HR	44.17%

Students who earned a D in their first attempt pass Calculus I on their second attempt at a rate higher than the class as a whole. However, students who earn an F, withdraw from the course after the 6-week drop date, or switch to hearer status in the course do not, in general, perform well on their second attempt in Calculus I. This leads us to the following transformative question: can we identify struggling students early enough in Calculus I to have an opportunity to redirect them toward a path that will lead them to success? The fortunate answer is that we can.

As part of our detailed examination of unsuccessful Calculus I students, we took a look at detailed course grade data for Calculus I in the Fall 2013 and Fall 2014 terms to see if we could identify with reasonable certainty whether or not a student would pass Calculus I based on his/her performance early in the semester. We only considered fall semesters because our fall and spring cohorts tend to be substantially different – in general, those who teach Calculus I find the fall cohort to be much stronger. We give our second Calculus I exam at the beginning of Week 8 – roughly at midterm – and when we only considered scores on Exam I, Exam II, and our mastery-based Basic Skills Differentiation exam (and exclude homework and lab quizzes), we obtained the following results.

Fall 2013 - Calculus I Comparison of Midterm and Final Grades			
	A, B, C after E2	D after E2	F after E2
Total Students	364	49	55
Passed (A, B, C)	299	4	0
Failed (D, F)	63	33	31
Withdrew	2	12	24

Fall 2014 - Calculus I Comparison of Midterm and Final Grades			
	A, B, C after E2	D after E2	F after E2
Total Students	342	35	51
Passed (A, B, C)	292	3	2
Failed (D, F)	48	32	36
Withdrew	2	0	13

While we were somewhat concerned about the number of students who were passing at midterm and did not pass the course (and we did make some changes in an attempt to help these students), we very clearly identified a group of students at exceptionally high risk for failure. Students who are earning a D or F at midterm do not, in general, pass Calculus I, and historic data shows that students who earn an F in Calculus I or choose to withdraw do not generally perform at satisfactory levels on future attempts at the course.

Now that we had identified a target audience, we had an even bigger question to answer: what can we do with these students for the remainder of the semester, knowing that they are not currently on a path to success in Calculus I? Our experience with Calculus I led us to believe that these students were struggling with Calculus I for a variety of reasons, many of which really had nothing to do with mathematics. While students often struggle with Calculus I due to a lack of foundational prerequisite knowledge in algebra and/or trigonometry, we also knew that many students in our target audience were struggling with inadequate study skills, poor self-management skills, deficient technical reading skills, and generally with adjusting to life in a collegiate environment.

Since college algebra and trigonometry are both prerequisite for Calculus I, most students struggling in Calculus I already have transcribed credit for both college algebra and trigonometry; in lieu of this, some received a waiver of the prerequisite as part of the initial freshman placement testing process. Thus, we cannot simply ask students struggling in Calculus I to retake college algebra and/or trigonometry. Furthermore, since their first experience with college algebra and trigonometry (whether taken on our campus or elsewhere) still left them unprepared for the demands of Calculus I, it wouldn't necessarily make sense to ask them to immediately retake Calculus I. In an attempt to address all of the academic and non-academic considerations surrounding these struggling students, we created a new course: Success for Calculus.

Success for Calculus is a pass/fail course which focuses on the use of college algebra and trigonometry skills within the context of calculus, providing students with the opportunity to improve their preparedness for future calculus coursework. Students who find themselves with a D or F at midterm in Calculus I and who meet other basic eligibility requirements based on class participation and attendance are given a one-time opportunity to switch from Calculus I into Success for Calculus. This is not mandatory, and students may elect to remain in Calculus I. Success for Calculus completely replaces Calculus I on the schedule and transcript of students electing to make the switch, and their performance in Calculus I for the first half of the semester constitutes one portion of the overall course grade in Success for Calculus. Students in Success for Calculus then spend the remainder of the semester reinforcing algebra and trigonometry skills while reviewing the calculus they have seen – but struggled with – during the first half of the term.

While Success for Calculus is, on paper, a mathematics course, the characteristics of students populating this course dictate that it be far more than simply a mathematics course. During the initial design process for the course, we actually spent far more time considering the non-mathematical elements of the course than the mathematical content of the course, and that has

continued to be true as we have refined the course. Our non-mathematical efforts in this course can generally be categorized as focusing on self-management and college readiness.

As we considered non-mathematical activities for this course, our primary goal was to equip students with the tools necessary to identify their own areas of weakness and develop a plan to address them. Many of the activities and strategies we incorporated into Success for Calculus are typically employed with students who begin their postsecondary experience with significant precollege remedial coursework, and although the literature on working with students at that level is extensive, not all of the strategies that are effective and/or necessary at that level will translate easily to students who have already reached calculus. We have incorporated many of the strategies, skills, and activities presented in Skip Downing's *On Course: Strategies for Creating Success in College and in Life* into the course (with some modifications for audience) to address the self-management and college readiness issues inherent in this group.

Some of the other activities we have developed for Success for Calculus are a direct response to observations we have made and comments we have overheard while walking around campus. On one occasion, two students were overheard commenting that they didn't have enough time to eat proper meals and get enough exercise, and they knew it was affecting their academic performance. To address this issue, we incorporated two activities. One activity, modified from *On Course*, asks students to track their activities on a calendar for a full week and then write a brief reflection on what they learned by looking at the calendar they created (Downing 2017). Students frequently discover that they are spending a significant amount of time on inconsequential activities. Another activity asks the students to track their diet and exercise for three days, and some of our students have discovered that they went over 24 hours without eating anything resembling a proper meal. Since the students have made these discoveries themselves, they are far more likely to do something about it than if we had simply given them a lecture on time management and proper nutrition.

Students struggling with college coursework often encounter significant (and sometimes clinically diagnosable) issues when taking high-pressure exams. To help students address these issues, we have partnered with the counseling staff on campus to provide a one-day discussion-oriented seminar which provides strategies for overcoming test anxiety and familiarizes the students with available resources on campus. For this activity, the faculty teaching Success for Calculus are asked to not attend in the hope that the students will be less hesitant to have a frank discussion with the counselor.

In addition to the non-mathematical college readiness issues impacting these students, another major challenge is that few of these students have been asked to read technical documents in high school and they are uncertain of how to approach something like a calculus or chemistry textbook. As the majority of our students are intending to major in engineering (or another STEM field), technical reading is a necessary skill, as evidenced by ABET General Criterion 3 (i), which calls for programs to develop in students "a recognition of the need for, and an ability to engage in life-long learning" (ABET 2016).

Much of the existing literature on student reading abilities in mathematics is a direct result of the work of Dr. Mary D. Shepherd. Shepherd has published extensively on reading skills and the

role of reading in college algebra and calculus classes. Her work discusses methods of guiding students through reading a mathematics textbook (Shepherd 2014), and she was kind enough to share many of her materials with us as we developed Success for Calculus. Using her work as inspiration, we developed reading guides to guide these students back through the portions of the calculus text which covered material they had already seen. These guided activities unlock the textbook as a resource and provide the students with another perspective on the material to complement the traditional lecture they saw in the first half of the semester and help prepare them for in-class collaborative activities on the material.

Success for Calculus was first offered in Fall 2015, and initial results have been quite positive. Because we are primarily concerned with how the students perform after they leave Success for Calculus, we will only consider students in the Fall 2015, Spring 2016, Fall 2016, and Spring 2017 cohorts so that students will have had at least 2 semesters since completing Success for Calculus to proceed through subsequent coursework.

Students who take Success for Calculus are being prepared to (re)take Calculus I in the following semester. While not all students in Success for Calculus choose to attempt Calculus I at Missouri S&T (or at all), students from these cohorts who attempted Calculus I at S&T were largely successful.

Grade in Calculus I after taking Success for Calculus						
Grade in Calc I →	A	B	C	D	F	Pass Rate
Grade in Success ↓						
Satisfactory	4.59%	25.51%	39.29%	19.90%	10.71%	69.39%
Unsatisfactory	0.00%	12.70%	26.98%	14.29%	46.03%	39.69%

For students who satisfactorily complete Success for Calculus, their pass rate of 69.39% brings them slightly above the historical average. For students who were almost certainly on the way to failing Calculus I, to have them passing at a rate slightly above the historical average is reassuring, but it's not enough to simply see how they do in Calculus I.

In Calculus II, unfortunately, the picture isn't quite as pretty.

Grade in Calculus II after taking Success for Calculus						
Grade in Calc II →	A	B	C	D	F	Pass Rate
Grade in Success ↓						
Satisfactory	7.38%	11.48%	37.70%	26.23%	17.21%	56.56%
Unsatisfactory	0.00%	12.90%	12.90%	38.71%	35.48%	25.81%

While the pass rate for students earning an S in Success is much lower than the historic averages, it's informative to note that many students in the spring cohorts of Success for Calculus have been choosing to take Calculus I over the summer at a different institution following their experience in Success. We isolated the students who earned satisfactory grades in Success for Calculus and went on to pass Calculus I at S&T, and while we are dealing with relatively small sample sizes at this point, we noted that every Success student who went on to earn an A in

Calculus II at S&T chose to complete Calculus I from S&T rather than at another institution. 11 of the 14 students earning a B in Calculus II also passed Calculus I at S&T.

In addition to preparing students for Calculus II and further mathematics coursework, Calculus I also feeds students into physics and, later, into foundational engineering courses in circuits and statics. While we did not have data for those courses as we were developing Success for Calculus, we are monitoring the performance of students who have taken Success and later moved into physics, circuits, and statics to compare them against the student body as a whole. We have a reasonable sample size of students who have progressed through Physics I, and a smaller but still interesting number who have reached Physics II, Statics and Circuits I. Due to sample sizes, we will only consider students who earned a satisfactory grade in Success for Calculus.

Calculus I is a direct prerequisite for Physics I. Some courses requiring Physics I as a prerequisite (such as statics) require a grade of C or better, while others (such as Physics II) only require a D or better. Thus, the C or better and the D or better pass rates are both presented for the physics courses.

Grades in Physics I							
Grade in Physics I	A	B	C	D	F	Pass Rate (C or better)	Pass Rate (D or better)
All students Spring 2014 – Spring 2018	19.01%	36.50%	29.08%	8.74%	6.68%	84.58%	93.32%
Satisfactory in Success for Calc	3.25%	28.57%	45.45%	14.29%	8.44%	77.27%	91.56%

Grades in Physics II							
Grade in Physics II	A	B	C	D	F	Pass Rate (C or better)	Pass Rate (D or better)
All students Spring 2014 – Spring 2018	28.32%	35.74%	26.08%	5.90%	3.95%	90.14%	96.05%
Satisfactory in Success for Calc	6.02%	33.73%	48.19%	9.64%	2.41%	87.95%	97.59%

While student performance in physics courses among students in the Success cohorts is lower than the student body as a whole (and the distribution of grades among those who pass tends to be skewed lower), students coming out of the Success cohort are still passing Physics I and II at impressively high rates.

When these students move on to Statics and to Circuits I, they continue to impress. For these courses, we are specifically concerned about a student earning a grade of C or better based on the requirements of the subsequent coursework.

Grades in Statics						
Grade in Statics	A	B	C	D	F	Pass Rate (C or better)
All students Spring 2014 – Spring 2018	24.15%	32.19%	27.81%	7.46%	8.38%	84.16%
Satisfactory in Success for Calc (n=61)	4.92%	26.23%	50.82%	6.56%	11.48%	81.97%

Grades in Circuits I						
Grade in Circuits I	A	B	C	D	F	Pass Rate (C or better)
All students Spring 2014 – Spring 2018	38.69%	28.47%	13.59%	9.67%	9.58%	80.75%
Satisfactory in Success for Calc (n=12)	8.33%	33.33%	25.00%	16.67%	16.67%	66.67%

In both cases, we see a much smaller percentage of students earning an A than the population as a whole, but the overall pass rate in Statics is very close to the population as a whole. Far fewer students have reached Circuits I, but the initial numbers are promising and as the sample size increases, it appears likely that the distribution will be similar to what has been seen in statics.

In addition to the feedback we receive by analyzing the data on Success for Calculus students, we have received very valuable feedback in the form of comments directly from these students. A great deal of this feedback has focused on the non-mathematical components of the course. In response to our diet and exercise activity, we received the following comment from a student:

I'm trying to work on basically EVERYTHING. I need to exercise more, eat better, and get out more. I have been working on it already, but I am still lacking. The progress I have made however has managed to help rid myself of my near constant stomach pains.

As neither of the authors are gastroenterologists, this is not the sort of feedback we are used to receiving from students, but it – along with the data we have presented – helps to confirm that we are, indeed, helping to unclog the calculus pipeline for these students and allowing them to find success in calculus and beyond.

References

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Biographical Information

Paul N. Runnion is an Associate Teaching Professor and the Director of Undergraduate Studies in the Department of Mathematics and Statistics at Missouri S&T, having joined the department in August 2011. After completing both his BS (2005) and MS (2007) in Applied Mathematics at the University of Missouri – Rolla, Paul spent four years as an instructor at Adirondack Community College in Queensbury NY before returning to Rolla. At Missouri S&T, Paul teaches a variety of undergraduate courses ranging from Intermediate Algebra through Differential Equations and Linear Algebra. Paul has led the department's Calculus Redesign initiative since 2013, and currently serves as the department's Calculus I coordinator. Paul is also the primary freshman advisor for the department. Outside of the world of mathematics, Paul is a bass/baritone in the St. Louis Symphony Chorus and is also active in the music program at his church.

Barbara J. Wilkins is an instructional designer in Educational Technology at Missouri S&T. She has a BA in History and a MS for Teachers in Mathematics. Involved in education since 1999, Barb has taught both history and mathematics in secondary schools, both in the classroom and online. She has also taught for a number of local colleges and universities, including the Missouri S&T Department of Mathematics and Statistics. In her role as instructional designer, Barb works with faculty across the S&T campus to develop curriculum, authentic assessment, and ensure course alignment, using research based best practices.