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# Identifying and Removing a Calculus Prerequisite as a Bottleneck in Clemson's General Engineering Curriculum

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## ABSTRACT

A review of prerequisites often reveals that reasons for requiring a prerequisite may no longer prevail due to curriculum or course changes. Based on a study of a curriculum bottleneck unrelated to required mastery, the prerequisite structure in Clemson University's General Engineering curriculum (the common first-year curriculum for all engineering students) was changed so that Calculus I could be taken in the second semester. Student record analysis shows both the magnitude of the bottleneck prior to the policy change and the effect on student enrollment practices after the policy change. Longitudinal studies show a statistically significant improvement in retention in engineering adding to the body of evidence that indicates that it is important to retention that students start college mathematics at a level for which they are prepared.

**Keywords:** freshman engineering, longitudinal study, mathematics readiness

## I. INTRODUCTION

Students entering the General Engineering program at Clemson University are required to take and pass calculus, which is typical of other engineering programs. Much research has been conducted that affirms the importance of a good experience in the first college mathematics course and its correlation with success in engineering [1, 2]. When it comes to freshman engineering programs, "there is a consensus that math is the largest stumbling block causing drop-out in the freshman year" [3]. Because calculus is the first math course in most engineering curricula, there is enormous pressure for students to be calculus ready when they arrive at college. In a study

of Purdue engineering students, Budny reported that students succeeding in pre-calculus had retention rates approximately equal to those of students succeeding in calculus [2, 4]. Clemson University's General Engineering program has many requirements that students must complete before they can select an engineering major, and passing Calculus I is a common barrier to curricular progress. It was hypothesized that if students could start ENGR 120, *Introduction to Engineering Problem Solving and Design*, before completing Calculus I, students would be able to progress in other parts of their curriculum and higher retention rates would result.

Before Fall 2000, Calculus I was a prerequisite for the second course in Clemson's General Engineering program (ENGR 120) as well as for the first course in physics. This caused a bottleneck in the curriculum—students could not progress in the engineering curriculum until passing Calculus I. Thus, failing or withdrawing from Calculus I, or not being prepared for it, had a much greater effect on a student's progress than failing other required courses. In order for a student to progress with their peers, a student would need to successfully complete three challenging courses (ENGR 120, Calculus II, and Physics) over the summer, a daunting task for students who are generally less prepared academically.

Moreover, students moving into an engineering major from General Engineering after May 15, 1996, have been required to have a grade of C or better in each course in the freshman curriculum except a humanities/social science requirement [5]. This means that, in Clemson's General Engineering curriculum, a grade of D is no better than an F or a W in terms of progress in the curriculum, thus aggravating the calculus bottleneck issue. The bottleneck caused by the calculus prerequisite policy had a number of consequences:

- students who continued in engineering were delayed;
- some students, faced with this fact, left engineering; and
- affected students occupied seats in fall (out-of-sequence) offerings of ENGR 120, causing the enrollment of those sections to be higher than desired.

## II. CALCULUS AS A PREREQUISITE

The most obvious reason to designate a course as prerequisite to another is when the courses are in sequence—it certainly makes sense for Calculus I to be a prerequisite for Calculus II. Even across departments, there are cases where one course must be completed in order to begin the material in another. As the material in the two courses changes, however, this relationship may weaken over time.

Another reason to designate a prerequisite is to establish certain checkpoints in a curriculum—this makes for less divergence of student course patterns and prevents a student from making too much progress in a curriculum that he or she is destined to abandon. Across the country, it is common for the first course in the calculus sequence to be a “gateway” to the engineering curriculum. Simply because calculus has such a high failure rate, there is the sense that, if someone is going to fail calculus and leave engineering, it might as well happen sooner rather than later. This appears to be the historical reason for making Calculus I a prerequisite for ENGR 120.

In order to serve students without compromising course objectives, the prerequisites for ENGR 120 and the first course in physics were reviewed in Spring 2000. This review of current instruction in both physics and ENGR 120 indicated that current curriculum expectations required only a co-requisite status of Calculus I. Following this review, a new policy was enacted, Fall 2000, which would allow students to take Calculus I as a co-requisite for ENGR 120 and enroll in physics with the permission of the instructor, which is granted pro forma.

Goals of the new policy were to:

- increase retention rates of freshman engineering students;
- correctly place students in their first math course (by reducing the pressure for the students to be calculus-ready at admission); and
- reduce the number of students taking ENGR 120 out of sequence.

We further believe that, while calculus is still a critical course in the curriculum, allowing students to take it concurrently with ENGR 120 (as a co-requisite) is actually of benefit—ENGR 120 serves to give calculus additional context. Now that students are taking Calculus I and the first physics course simultaneously, the General Engineering faculty are working to create linkages between

those courses and the ENGR 120 curriculum. There would certainly be a benefit to achieving a just-in-time delivery of calculus and physics topics [6, 7].

### III. REVIEW OF STUDENT RECORDS

Student records data summarized in Table 1 were analyzed to determine changes in student behaviors under old and new academic policies. From Table 1 the “number of students enrolled in Calculus I in the Fall of their cohort year” was defined by counting only students in the General Engineering curriculum who were new freshmen or transfers in the given cohort year. Students who drop a course at Clemson during the first two weeks of the semester may do so without grade penalty (a policy that is common at many academic institutions) [8]. At Clemson, Calculus I students dropping within this period may switch to a lower math class, even though it may be beyond the formal period for adding a class. Students who change math courses in this manner are treated as if they originally enrolled in the second math course.

The policy of Calculus I (106) as a co-requisite versus a prerequisite was analyzed by grouping the prerequisite one-year retention rates (1996–1999) and comparing them with the co-requisite one-year retention rates (2000–2002) for those students who received a D/F/W in Calculus 106. The hypothesis was that one-year retention rates would be greater in the years following the policy change. Analysis of these two groups revealed a statistically significant difference in the groups. Retention rates after the change in calculus policy were higher than rates before the change in policy ( $p < 0.05$ ). The stable proportions of calculus-ready students and first-time passage rates discussed earlier suggest that the observed improvement is not due to changes in either parameter. With limited data available after the policy change, analysis was conducted on

	1996	1997	1998*	1999	2000**	2001	2002
Total number of new freshman and transfer students enrolled in the General Engineering curriculum in given cohort year	658	664	674	761	777	761	727
Number of students enrolled in Calculus I in the fall of their cohort year.	342	368	393	451	485	458	369
Number of D/F/W in 106 in the fall of cohort year	95	125	147	174	196	159	107
Percentage of total enrollment in 106 in fall Cohort	28%	34%	37%	39%	40%	35%	29%
Number failed and still in engineering next fall	45	64	100	87	130	88	62
Number failed and still in engineering two falls later	31	50	42	49	94	60	-
One-year retention rate of students who failed first math	47%	51%	68%	50%	66%	55%	58%
Two-year retention rate of students who failed first math	33%	40%	29%	28%	48%	38%	-

\*After 1998, students needed a grade of C or better in required prerequisite courses to continue in the curriculum.

\*\*In 2000, ENGR 120’s calculus prerequisite was changed to a co-requisite.

Table 1. Historical perspectives of Calculus I (Calculus 106).

two-year retention rates again grouping years (1996–1999) and (2000–2001). The results were likewise statistically significant and in line with the one-year retention results ( $p < 0.001$ ).

Table 2 shows the historical performance of students who enrolled in Pre-Calculus 103/105 as their first college math course (103 is a course with applications in analytical geometry and trigonometry and 105 is a course combining college algebra and pre-calculus). A similar analysis was conducted for the Pre-Calculus 103/105 students. The hypothesis again was that one-year retention rates would be greater in the years following the calculus as a prerequisite policy change. Analysis of these two groups revealed a statistically significant difference in the groups. Retention rates after the change in calculus policy were higher than rates before the change in policy ( $p < 0.05$ ). Two-year retention rates were also statistically significant ( $p < 0.05$ ).

A comparison of students who passed Pre-Calculus 103/105 (those who earned an A/B/C in the course) and students who failed Calculus 106 (those who earned a D/F/W in the course) was also conducted. One-year and two-year retention rates were analyzed for both populations. It was hypothesized that students who passed Pre-Calculus 103/105 would have higher retention rates than those students who failed Calculus 106. Both one and two-year retention rates for students passing 103/105 were statistically significantly higher than students failing Calculus 106 ( $p < 0.01$ ). These results would seem to confirm those of the Purdue study on “high-risk”

courses conducted by Budny et al. [2] and the general notion that students should be placed in courses at their appropriate skill level.

#### IV. NEW ENROLLMENT POLICY

One of the goals of the policy change was to reduce the number of students taking ENGR 120 out of sequence (fall enrollment). Table 3 shows the enrollment of ENGR 120 in both the spring and fall semesters. The out of sequence, or fall, enrollment for both students failing Calculus I the previous fall and those students who passed Pre-Calculus the previous fall have been drastically reduced. The total fall enrollment in each case is shown. There are two benefits to reducing the fall enrollment—the presence of a large number of students who have already failed calculus is harmful to maintaining heterogeneous academic ability, which is known to enhance educational outcomes for all students [9], and a reduction in the number of sections of ENGR 120 taught in the fall, which helps balance the teaching load for General Engineering faculty.

The steady growth in the number of students failing Calculus I and losing a year in the engineering curriculum is apparent from 1996–1999, as is the rapid reduction of that group after the implementation of the new policy. There is also a notable decline in the number of students that fail Calculus I and enroll in ENGR 120 in the spring, which seems to confuse the issue. The size of those

	1996	1997	1998*	1999	2000**	2001	2002
Number of A/B/C in 103 or 105 in fall of cohort year	44	31	12	39	36	50	58
Percentage of total enrollment in 103/105	59%	54%	24%	64%	48%	59%	64%
Number of A/B/C in 103/105 and still in engineering next fall	23	20	9	24	22	32	47
Number of A/B/C in 103/105 in engineering two falls later	15	13	7	17	20	26	-
One-year retention rate of students who passed Pre-Calculus 103/105	52%	65%	75%	62%	61%	64%	81%
Two-year retention rate of students who passed Pre-Calculus 103/105	34%	42%	58%	44%	56%	52%	-

Table 2. Historical perspectives of Pre-Calculus (MthSC 103 and 105).

Cohort Year	1996	1997	1998	1999	2000	2001	2002
Failed Calculus 106 and enrolled in ENGR 120 in fall of following academic year	19	36	39	48	16	8	3
Failed Calculus 106 and enrolled in ENGR 120 in the spring of the academic year	*	*	*	*	124	103	57
Passed Pre-Calculus 103/105 and enrolled in ENGR 120 in fall of following academic year	17	15	6	18	6	2	5
Passed Pre-Calculus 103/105 and enrolled in ENGR 120 in the spring of the academic year	*	*	*	*	18	38	43
Total ENGR 120 enrollment in fall of following academic year	140	135	170	163	139	108	76

\* In 1996-1999, Calculus I was a prerequisite for ENGR 120; spring enrollment was not an option.

Table 3. Historical enrollment of Engineering 120.

numbers indicates that more students who fail calculus on their first attempt are remaining in engineering. The decline in 2001–2002 is the result of a reduction in the number of students failing Calculus I due to changes implemented by Clemson’s Mathematical Sciences department. The increase in the number of students passing pre-calculus and enrolling in ENGR 120 the following semester is related—the most significant change implemented was an improved placement practice, which caused the least prepared students to take pre-calculus instead of calculus. Shifting less prepared students from calculus to pre-calculus improves the passing rate of each class.

## V. NEW POLICY AND LONG-TERM RETENTION

To some it may appear that this new policy postpones the inevitable—keeping students in engineering who will ultimately fail. Historical data seem to support this conclusion, as the percentage of students who earn an unsatisfactory grade (D/F/W) in first-semester Calculus on their first attempt that eventually graduate in engineering has been very low in the past (~ 29 percent, compared to ~ 65 percent graduation rate for students with C or better in their first math course). The General Engineering faculty proposes that the historical data are biased by the extreme consequences to a student’s curricular progress described earlier—that many students who failed first-semester Calculus simply gave up rather than trying to get back on track.

Changing calculus to a co-requisite to our second-semester engineering class encourages progress and retention in engineering. There are data to support these findings.

- Of the 196 students in the 2000 cohort who failed first-semester Calculus, 140 took the course over again in the spring.
- Of the 140 that took the course over again, 62 passed it in that attempt.
- The distribution of calculus grades of the 140 students retaking the course increased from a corporate average grade point ratio (GPR) of 0.5, on a 4.0 scale, in the first attempt (W does not count in GPR calculations) to a GPR of 1.2 in their second attempt in the spring semester.
- One-year retention of students failing first-semester Calculus is higher in the years following the change in policy.
- Retention rates of students taking and passing a Pre-Calculus course have higher one and two-year retention rates than students who fail Calculus I.

In addition to retention gains supported by the ability to progress in the curriculum, students should also benefit from seeing the big picture—finding out more about what engineering is, giving them a reason to work toward success in calculus. We may be able to test this hypothesis using longitudinal data from the Cognitive Profile Inventory [10], an instrument that many of Clemson’s engineering students have completed.

## VI. CONCLUSIONS

In removing Calculus I as a prerequisite, we have allowed students to progress in the General Engineering curriculum, even though they may already have exhibited a significant indicator of

not succeeding in engineering. Certainly, not all who retake Calculus I will succeed in passing on the second attempt. As is the case with most policies, we must weigh the risk of granting students an opportunity at which they will fail against the risk of preventing students from having an opportunity at which they could succeed. The data from this study lead us to conclude that the shift in policy helps a large number of students.

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