STUDENTS WHO SWITCH OUT OF CALCULUS AND THE REASONS THEY LEAVE

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A substantial percentage of college students who enrol in Calculus I intending to take more calculus decide at the end of the semester not to continue with calculus. This represents a huge loss in terms of the need for more students to pursue a major in one of the science, technology, engineering and mathematics (STEM) disciplines. In this report we examine the characteristics of STEM intending students who begin their post secondary studies with Calculus I and either persist or switch out of the calculus sequence, and hence either remain or leave the STEM pipeline. The data used for this analysis comes from a unique, in depth national survey aimed at identifying characteristics of successful programs in college calculus.

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Introduction

As detailed in the recent report in the USA from the President's Council of Advisors on Science and Technology (PCAST, 2012), there is tremendous need for more students with degrees in science, technology, engineering, and mathematics (STEM). For example, the PCAST report predicts that, over the next decade, approximately 1 million more STEM graduates above and beyond the current level of STEM graduate production will be needed in order to meet the demands of the national workplace. One strategy for meeting this need is to increase the retention of STEM majors. In fact, the PCAST report predicts that simply increasing the retention of STEM majors from 40% to 50% would go a long way to meeting this need.

As reported by Seymour (2006), students leave STEM majors primarily because of poor instruction in their mathematics and science courses, with calculus often cited as a primary reason. Therefore, in order to develop more successful retention strategies, the field is in need of a deeper understanding of what distinguishes those who continue with calculus from those who do not.

The purpose of this report is to examine the characteristics of STEM intending students who begin their post secondary studies with Calculus I and either persist or switch out of the calculus sequence, and hence either remain or leave the STEM pipeline. The data used for this analysis comes from a unique, in depth national survey aimed at identifying characteristics of successful programs in college calculus. In this report we answer the following three research questions: (1) What is the profile of students who choose not to continue with calculus? (2) What are the reasons that students give for switching out of calculus? (3) What characterizes the behavior of switchers and the behavior of their instructors?

Background

Researchers in Higher Education have extensively studied factors related to student retention at the post-secondary level, often focusing on the effects of student engagement and integration on persistence (e.g., Kuh et al., 2008; Tinto, 1975, 2004). According to Tinto's integration framework (1975), persistence occurs when students are socially and academically integrated in the institution. This integration occurs through a negotiation between the students' incoming social and academic norms and the norms of the department and broader institution. From this perspective, student persistence is viewed as a function of the dynamic relationship between the student and other actors within the institutional environment, including the classroom environment.

Guided in part by this theoretical and empirical work in higher education, this paper reports on a five-year study of Calculus I instruction at colleges and universities in the United States. The first phase was a large-scale national survey of Calculus I instruction at two- and four-year colleges and universities. The survey was restricted to what is known as "mainstream" calculus, the calculus course that is designed to prepare students for the study of engineering or the physical sciences.

The second phase of the study consists of case studies examining Calculus I instruction at seventeen colleges and universities identified as having a notable measure of success with their Calculus I program. Success was defined in terms of both the percentage of students who had successfully completed the course and the percentage of students who maintained or increased their interest in continuing the study of mathematics beyond Calculus I, controlling for the varying academic strengths and interests of the entering students at different institutions.

Methods

The large-scale national survey of mainstream Calculus I instruction was conducted across a stratified random sample of two- and four-year undergraduate colleges and universities during the fall term of 2010. Preparation for the surveys included a literature review leading to a taxonomy of potential dependent and independent variables followed by constructing, pilot testing and refining the survey instruments (Lodico, Spaulding, & Voegtle, 2010; Szafran, 2012).

A total of six on-line surveys were constructed: one for the calculus coordinator; two for the calculus instructors of which one was administered immediately before the start of the course and the other immediately after it ended; and three for the students of which one was administered at the end of the second week of the course, one just before the end of the course, and the last one year later to those students who had volunteered their email addresses. In addition, instructors reported on the distribution of final grades and submitted a copy of the final exam. All surveys were completed online, and no incentives were given for completing the surveys. For the analysis reported here, only the three student surveys were used.

The survey was sent to a stratified random sample of mathematics departments following the selection criteria used by Conference Board of the Mathematical Sciences (CBMS) in their 2005 Study (Lutzer et al, 2007). Following the strategy of CBMS, we separated colleges and universities into four types, characterized by the highest mathematics degree that is offered: Associate's degree, Bachelor's degree, Master's degree, and Doctorate. Within each type of institution, we further divided the strata by the number of enrolled full time equivalent undergraduate students, creating from four to eight substrata. We sampled most heavily at the institutions with the largest enrolments. In all, we selected 521 colleges and universities: 18% of the Associate degree colleges, 13% of the Bachelor's degree colleges, 33% of the Master's degree universities, and 61% of the Doctoral universities. Of these, 222 participated: 64 Associate degree colleges (31% of those asked to participate), 59 Bachelor degree colleges (44%), 26 Master's degree universities (43%), and 73 Doctoral universities (61%).

There were 660 instructors and over 14,000 students who responded to at least one of the surveys. There is complete data (the first five surveys completed and linked with each other) for 3103 students enrolled with 309 instructors at 125 colleges or universities. However, in order to

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answer our research questions we did not need to restrict ourselves to the completely linked data set. Instead, we needed either a student end of term survey or follow up survey.

Results

Depending on a student's initial intention to continue with calculus and whether they switched or persisted with their intention, we used multiple questions across surveys to classify students into four categories: Culminaters, Persisters, Switchers, and Converters. Culminaters are those students who began and ended the course not intending to take Calculus II. These students typically only need Calculus I for their major. Persisters were those students who initially intended to take more calculus and did not change this intention. Switchers, on the other hand, were those students that started Calculus I intending to take more calculus, but then by the end of the term (or one year later) changed their plans and opted not to continue with more calculus. Finally, Converters were those students who initially did not intend to take more calculus but by the end of term changed their mind and wanted to continue taking more calculus. Out of a total of 7260 students for which we could code in terms of one of the four categories, there were 1,789 Culminators, 4,710 Persisters, 671 Switchers, and 90 Converters.

Persisters and Switchers constitute the two main categories of STEM intending students. For STEM intending students in our sample, we found that 12.5% of them were classified as Switchers. In order to improve retention of STEM majors, we need to understand how Switchers and Persisters are similar and different. The following analysis focuses on comparing Persisters and Switchers.

To address our first research question, we compared Switchers and Persisters across a number of variables. In this report we provide results from gender, ethnicity, career path, and academic preparation. Data for each of these variables was collected on the start of the term survey.

Of the students who reported gender information, 41.5% (1317) of STEM intending students were female and 48.5% (1856) were male. In comparison to males, the percentage of female Switchers is significantly higher, indicating that women are more likely to leave a STEM major. Specifically, only 11% of 1856 males were identified as Switchers whereas 20% of the 1317 females were Switchers (χ^2 (df = 1, n = 3173) = 49.14, p < .001). Contrary to the observed differences among gender, there were no statistically significant differences by ethnicity (χ^2 (df = 7, n = 3169) = 3.210, p = 0.865).

We also analyzed differences by career path. Switcher rates differed significantly by career choice, with Engineers switching at very low rates (5.9%) and the biological sciences switching at much higher rates than average (24.8%). These results made us interested to know how this was related to differences in gender. As shown in Table 2, the switching behaviors within career choices varied significantly based on gender (χ^2 (df = 15, n = 3141) = 102.9, p < .001). For example, in the biological sciences almost 30% of females switched while only 17% of males did so. Similarly, in the fields of math, physical sciences and computer science women switched out at two to three times the rate of males in the same fields.

Table 1: Relation Between Career Choice and Gender

	Male		Female	
Career Choice	Persister	Switcher	Persister	Switcher
Biological Sciences	82.55%	17.45%	70.35%	29.65%
Life, Earth, and Environ. Sciences	81.33%	18.67%	82.40%	17.60%
Math and Physical Sciences	95.04%	4.96%	85.88%	14.12%
Engineering	94.45%	5.55%	93.11%	6.89%
Computer Science	88.39%	11.61%	77.27%	22.73%
Math or Science Teacher	86.84%	13.16%	82.98%	17.02%

We addressed academic preparation by examining coursework taken in secondary school, Advance Placement (AP) pass rates, SAT scores, self reported algebra skills, and end of term self assessment of preparation. We conjectured that Switchers were less well prepared than Persisters when they began their postsecondary study of Calculus I. In broad terms, this conjecture turned out not to be the case. There was no statistically significant difference between the percentages of Switchers compared to Persisters who took Calculus in high school (χ^2 (df = 1, n = 2676) = 2.12, p = .15). Similarly, the mean SAT score for Switchers (M = 642, SD = 86.97) was not significantly different than that for Persisters (M = 651, SD = 75.823), t(2710)= 2.233, p = .076. It was the case, however, that Persisters had significantly higher mean AP Calculus BC scores (but not AB scores) than Switchers. However, the number of students who took the BC exam and enrolled in Calculus I was relatively small.

To address our second research question (reasons why Switchers are choosing to not continue on in calculus), we looked at Switchers' and Persisters' responses to an end of the term survey question in which students could check off multiple reasons for not continuing with calculus. The most frequently given reason for not taking Calculus II was a changed major, with 38.9% of Switchers selecting this option. Because students were allowed to select multiple responses, we were interested to know the overlap between reasons. Specifically, we were interested in the other reasons Switchers who changed majors gave for not continuing on in calculus. As shown in Table 2, this analysis shows that of the Switchers who replied that they are not taking Calculus II because they changed their major, 31.4% also replied that their experience in Calculus I made them decide not to take Calculus II.

Table 2: Reasons Switchers Give for Not Taking Calculus II

Reason for not taking Calculus II	
My experience in Calculus I made me decide not to take Calculus II	31.4%
To do well in Calculus II, I would need to spend more time and effort than I can afford	28.7%
I have too many other courses I need to complete	27.6%

I do not believe I understand the ideas of Calculus I well enough to take Calculus II	18.8%
My grade in Calculus I was not good enough for me to continue to Calculus II	11.5%
I never Intended to take Calculus II	6.1%

This result is consistent with Seymour's (2006) finding that students frequently leave STEM majors because of their experience in their introductory courses, including Calculus I. This finding necessitates a better understanding about the nature of the Calculus I experience, which leads to our third research question.

For the third research question, we investigated several different variables to understand students' experiences in Calculus I, including student behavior in and out of class and student description of their Calculus I instruction. For example, students were asked to report how frequently they did each of the following activities during class, from never (1) to every class session (5): contributed to class discussions, were lost and unable to follow the lecture or discussion, asked questions, and simply copied whatever was written on the board. For each of these questions, we conducted an independent-samples t-test to compare responses for Switchers and Persisters. As can be seen in Table 3, there was a significant difference in the responses for the amount of time spent contributing to class discussions between Switchers and Persisters, time spent lost and unable to follow the lecture or discussion, and time spent simply copying whatever was written on the board, but there were not significant differences between Switchers and Persisters on time spent asking questions. These results indicate that Switchers report spending less time in class contributing to class discussion, more time lost and copying down what is written on the board, and the same amount of time asking questions as reported by the Persisters. Taking these together, Switchers report being *less engaged* than Persisters during class. This is despite the fact that their mathematical preparation was not significantly different from that of Persisters.

Table 3: Student Reports of in-class Behavior.

During Class:	**Persister**	**Switcher**
I contributed to class discussions.**+	2.69 (1.25)	2.47 (1.17)
I was lost and unable to follow the lecture or discussion.**	1.89 (0.99)	2.18 (1.02)
I simply copied whatever was written on the board.**	2.86 (1.36)	3.26 (1.32)
I asked questions.+	2.38 (1.12)	2.34 (1.07)

Note. * = $p \leq .05$, ** = $p \leq .001$, + indicates that Persister mean greater. Standard Deviations appear in parentheses below means.

In terms of out of class behavior, we found that similar to Persisters, about 70% of Switchers worked at a job for at most five hours per week. Moreover, the vast majority of Switchers spent about the same amount of time studying calculus as did Persisters. Moreover, a statistically significant greater percentage of Switchers reported visiting their instructor's office hours either weekly or monthly (56.2% versus 48.1%) and going to tutoring on a weekly basis (25.6% versus

15.2%) than Persisters. Thus, this data suggests that Switchers are making the effort to be successful. Compared to Persisters, they do not work more on an outside job, they are studying as much or more, and they are seeking academic help more so than Persisters. All of this, together with the reasons that Switchers give for not continuing on with Calculus, suggests that a closer look at what happens in the classroom is warranted.

To examine student reported classroom instruction, we conducted a factor analysis on the questions on the end of the term survey pertaining to instructor pedagogy. The 27 items of the student end of term survey were subjected to principal components analysis (PCA). Prior to performing PCA, the suitability of data for factor analysis was assessed and supported the factorability of the correlation matrix. Principal component analysis revealed the presence of four components with eigenvalues exceeding 1, though inspection of the scree plot revealed a clear break after the second component. The two-component solution explained a total of 46% of the variance, with Component 1 contributing 36% and Component 2 contributing 10%. There was a weak positive correlation between the two factors ($r = 0.250$). The results of the analysis are used to create new variables representing these components, hereafter referred to as "Good Teaching" and "Progressive Teaching."

"Good Teaching" included questions where students rated their instructor on the extent to which he or she listened carefully to their questions and comments, allowed time for them to understand difficult ideas, presented more than one method for solving problems, asked questions to determine if they understood what was being discussed, discussed applications of calculus, encouraged students to seek help during office hours, frequently prepared extra material, gave assignments that were challenging but doable, graded exams fairly, and gave exams that were a good assessment of what was learned. "Progressive Teaching" included questions where students rated their instructor on the extent to which he or she required them to explain their thinking on homework and exams, required students to work together, had students give presentations, held class discussions, put word problems in the homework and on the exams, put questions on the exams unlike those done in class, and returned assignments with helpful feedback and comments.

Based on the frequency distributions, we grouped these two variables into thirds, representing low, medium, and high levels of Good and Progressive Teaching. Table 4 shows how low and high levels of Good Teaching and low and high levels of Progressive Teaching relate to the percentage of students who were Switchers. The percentages in Table 4 should be compared to 14.8%, which is the switching percentage for the sample of students who responded to the instructor pedagogy questions on the end of term survey.

Table 4: Switching Rate for Low and High Levels of Good and Progressive Teaching

	Low Good Teaching	High Good Teaching
Low Progressive Teaching	18.8%	13.6%
High Progressive Teaching	14.0%	8.9%

As shown in Table 4, the type of instruction seems to make a significant in student retention (χ^2 (df = 2, n = 3294) = 10.124, p = .006). "Progressive" teaching, which includes instructional approaches that more actively engages students, is associated with lower switching rates. Indeed, a high level of progressive teaching coupled with high levels of good teaching reduces the switching rate from 18.8% to 8.9%. This finding is consistent with Tinto's integration framework

(1975), which connects persistence to students' social and academic integration; engaging students in class are at once integrating them into the academic community, both socially and academically. These findings indicate that Switchers reported having different classroom experiences than Persisters. Their instructors were less likely to actively engage them (working by themselves or with a classmate on problems, having a whole class discussion, asking students to explain their thinking, etc.), they were less likely to contribute to class discussion, and more frequently found themselves lost in class.

Ellis, Kelton and Rasmussen (2013) conducted a follow up analysis to determine if the above results are due to Switchers and Persisters being in different classes, or instead if these students are in the same class but having different instructional experiences. They found that student reports within a class are on average in agreement with instructor reports. In addition, they found that Switchers reported being less engaged than Persisters within the same classes, even when controlling for gender, major, socioeconomic status, and preparation.

Additional studies that include classroom observations are needed to further study the effect of instructional approach on student retention in a STEM major. Nonetheless, these findings are consistent with prior research summarized in the PCAST report and with the seminal work of Seymour and Hewitt (1997).

Conclusion

Up until now there has been little large-scale data collected on who elects to study Calculus I at a university. Additionally, little is known about the effect of Calculus I on student intention to pursue a career in mathematics, science, or engineering. Even information as basic as the US national success rate and the percentage of students in university Calculus I who successfully complete the course has not been reported. This large-scale national study is making a significant contribution to what we know about Calculus I (for example, see Bressoud, Carlson, Mesa, & Rasmussen, 2013).

Findings from this report illuminate the types of students who are switching out of STEM majors, as well as their experiences in Calculus I. It is clear that many of the students who intended to take Calculus II but did not were hard working and well prepared. When asked why they no longer intended to take Calculus II, Switchers reported not continuing with calculus because they changed their major, citing a negative experience in Calculus I and spending too much time and effort in Calculus I as the second and third most responses. When we look more deeply at their experience in Calculus I, Switchers and Persisters report different experiences. This suggests that instructional variables such as actively engaging students, having students explain their reasoning, etc. may make a difference in retaining STEM majors. While many may have conjectured that such a finding is the case, this is the first large scale, national study in calculus to provide data for this position.

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