Student perceptions of pedagogy and persistence in calculus

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Abstract Previous reports show that not only are too few students pursuing Science, Technology, Engineering, or Mathematics (STEM) fields, but also many who originally intend to pursue these fields leave after their experiences in introductory STEM courses. Based on data gathered in a survey conducted across the United States, we present an analysis of 1684 STEM intending students and 330 non-STEM intending students enrolled in introductory Calculus in Fall 2010. Prior analyses of this data have shown that students who originally intended to take Calculus II and then no longer do at the end of their Calculus I term report being less engaged by their instructor during class. This result led us to ask the following question: Are students who persist in calculus in different classes than those who don't, or are they experiencing the same classes differently? In order to explore this question, we first compare student and instructor reports of the frequency of twelve types of pedagogical activity, such as lecture, whole class discussion, and showing students how to work specific problems. We then present descriptive and univariate analyses of the relationship of calculus persistence to student demographics, background characteristics, and reported frequencies of pedagogical activities. Finally, we develop regression models that control for the group effect of course enrollment to understand how perceiving low levels of various pedagogical activities within a class might be associated with calculus persistence.

Keywords: Post-Secondary Education, Instructional activities and practices, Data Analysis and Statistics, Calculus instruction, Student persistence

1 Introduction

This study explores the relationship between student reports of pedagogy in Calculus I across the United States (US) and their intention to continue with the calculus sequence. Calculus I in the US is viewed as a university-level course that typically covers limits, rules and applications of the derivative, the definite integral, and the fundamental theorem of calculus. In the US and elsewhere, calculus often functions as a filter, preventing large numbers of students from pursuing a career in science, technology, engineering or mathematics (STEM). Instructional experience is a major factor contributing to a student's decision either to continue or discontinue with the calculus sequence (Seymour and Hewitt 1997). Because of this, a better understanding of the relationship between students' instructional experiences in Calculus I and their decisions to continue taking additional calculus is needed to improve student success in calculus and their continued interest in STEM careers. Moreover, for those students whose culmination of their mathematical studies is Calculus I, improved instruction might leave them with a better appreciation of calculus and mathematics, and potentially the desire to take more calculus than originally intended in order to pursue a STEM degree. Previous analysis has shown that student reports of more academically engaging pedagogy, such as whole class discussion, students explaining their thinking, and working together in groups, is related to calculus persistence among STEM intending students (Rasmussen and Ellis 2013). These results raise the question of why students who go onto Calculus II report being more engaged in class than students who don't: Are they in different classes, or are they experiencing the same classes differently?

2 Theoretical Background

Researchers in higher education have studied factors related to student retention at the post-secondary level, often focusing on the effects of student engagement on persistence (Kuh et al. 2008; Tinto 1975, 2004). According to Tinto's framework (1975), persistence occurs when students are socially and academically integrated in the institution. Numerous studies, across a variety of settings and types of students, show that involvement and engagement with peers and instructors increases persistence onto graduation. This integration occurs through a negotiation between the students' incoming social and academic norms and characteristics and the norms and characteristics 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.

Tinto highlights that this integration is most important during students' first college year, a time "when student membership in the communities of the campus is so tenuous" (Tinto 2004, p. 3). For most US students, Calculus I is taken in their first year in college. As such, the academic and social engagement that students are (or are not) exposed to during calculus plays a role both in students' decision to persist in their intended majors as well onto graduation in general. In this study we examine how student engagement in the classroom is related to a student's choice to continue onto Calculus II, while controlling for various student characteristics. Thus we focus on how the classroom experience is related immediately to students' persistence onto Calculus II.

Calculus I is not only an integral part of all STEM fields, but it has also been shown to be a main contributing factor to students' decisions to leave STEM disciplines (Seymour and Hewitt 1997). Recent studies show that although the work-force demand for STEM majors has been increasing from 1971 to 2009, the number of students pursuing STEM majors remains constant at around 30% nationwide (Carnevale, Smith, and Melton 2011; Hurtado, Eagan, and Chang 2010). In addition, the need for more students to pursue a STEM related degree is exacerbated by the fact that a low percentage of STEM intending students persist in obtaining a STEM degree. These trends may have economic implications. For example, a recent report from the US President's Council of Advisors on Science and Technology (PCAST 2012) states that an increase in STEM students is the determining factor for continued economic growth. This 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 US workplace.

The Higher Education Research Institute (HERI) has determined that between 40% to 60% of STEM intending students obtain a STEM degree within six years (Hurtado, Eagan, and Chang 2010). Thompson and his colleagues (2007) found that only 50% of STEM intending students enrolled in first-semester calculus at a large research I university went on to complete second-semester calculus, and only 30% of these students completed multivariable calculus. Rasmussen and Ellis (2013) recently estimated that 87.5% of STEM intending Calculus I students nationwide intended to take Calculus II after completing Calculus I. Of course there are a number of reasons why students leave STEM majors, but one reason often cited by students is poor instruction in their introductory mathematics and science courses, with calculus often cited as a primary reason (Rasmussen et al. 2013; Seymour 2006; Thompson et al. 2007).

These reports indicate the critical need to better understand students' calculus experiences.

As part of a large, US project in which the present study is situated, Rasmussen and Ellis (2013) investigated the demographic profile and classroom experiences of STEM intending students who do and do not persist onto Calculus II, identified as persisters and switchers, respectively. Of the 5381 STEM intending students enrolled in Calculus I at the time of the study, 12.5% no longer intended to take Calculus II at the end of Calculus. When asked why, 38.9% of the switchers answered that they changed their major and were no longer required to take Calculus II. Of these students, 31.4% also responded that an additional reason for their changed intention was their experience in Calculus I.

In order to understand their classroom experience, the authors conducted a factor analysis on the questions on an end-of-term survey pertaining to instructor pedagogy. This resulted in two groupings of classroom instructional activities, which were labeled as "Good" and "Progressive" teaching. Good teaching included activities such as listening carefully to students' questions and comments, allowing time for them to understand difficult ideas, presenting more than one method for solving problems, asking questions to determine if they understood what was being discussed, discussing applications of calculus, and encouraging students to seek help during office hours. Progressive teaching includes instructional approaches that more actively engage students, such as requiring them to explain their thinking on homework and exams, requiring students to work together, having students give presentations, and holding class discussions.

Progressive teaching is associated with lower switching rates. Indeed, high levels of progressive teaching coupled with high levels of good teaching reduce the switching rate from 15.3% to 11.7%. 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.

These results beg the question: Are switchers and persisters reporting different classroom experiences because they are in different classes, or are they experiencing the same classes differently? If the latter, how does their choice of whether or not to continue in the calculus sequence relate to the ways in which they experience Calculus I instruction? Additionally, what about the students who began and ended Calculus I not intending to take more calculus (we refer to such students as Culminaters) and those students who began Calculus I not intending to take more calculus but who decided to continue with the calculus sequence at the end of the term (we refer to such students as Converters)? With this background now in place, we rephrase the purpose of this paper in the following research question: How is student perception of pedagogy within a class associated with end of term intention to take Calculus II, and thus their status as a Persister or Switcher, Culminater or Converter?

3 Methods

Data for this study come from a large US survey of mainstream Calculus I instruction that was conducted across a stratified random sample of two- and four-year undergraduate colleges and universities during the Fall term of 2010.

Mainstream calculus refers to the calculus course that is designed to prepare students for the study of engineering or the mathematical or physical sciences. Six online surveys were constructed: (a) one for the calculus coordinator; (b) two for the calculus instructors, administered at start and end of term respectively; (c) two for the students in the course administered at start and end of term respectively; and (d) a student follow-up survey administered one year later to those students that volunteered their email addresses. Survey design was informed by 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, and Voegtle 2010; Szafran 2012). The stratified random sample for the surveys followed the selection criteria used by Conference Board of the Mathematical Sciences (CBMS) in their 2005 study (Lutzer et al. 2007). In all, we selected 521 colleges and universities, 222 of which participated: 64 two-year colleges (31% of those asked to participate), 59 undergraduate colleges (44%), 26 regional universities (43%), and 73 national universities (61%). There were 660 instructors and over 14,000 students who responded to at least one of the surveys.

For the present study, we restricted the data to students who responded to both pre- and post-term surveys and whose instructors did as well. Data from two institutions were also removed from the data set because information specifying which courses these students were enrolled in was unavailable. We further excluded all data from any class for which less than 5 students responded to the end-of-term survey. These restrictions resulted in a study population of 2014 students with 166 instructors from 95 institutions.

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:, Persisters, Switchers, Culminaters, and Converters. Persisters are those students who initially intended to take more Calculus and did not change from this intention at the end of the term (or one year later). 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. 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 and hence are not STEM intending. 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.

Table 1 provides the total number of students in each of these four categories. Because Calculus II is a required course for most (if not all) STEM majors, we use the intention to take Calculus II as a proxy for being a STEM intending student. Thus, Switchers and Persisters are STEM intending while Culminaters and Converters are non-STEM intending (as judged from the start of the term).

Table 1 Proportion of STEM intending and non-STEM intending students who continue taking calculus

Type of student		No. (%) of students in large data set	No. (%) of students in restricted data set
STEM intending	Persister	4,710 (87.5%)	1432 (85%)
	Switcher	671 (12.5%)	252 (15%)
Non-STEM intending	Culminater	1,789 (95.2%)	288 (87.3%)
	Converter	90 (4.7%)	42 (12.7%)[1]

In this study we first investigate the univariate relationships between end-of-term calculus intention and (a) student demographics, (b) student preparation, and (c) reported pedagogical activities. For the student demographics, we examine students' gender, race/ethnicity, socioeconomic status as marked by parent or guardians' education level, and intended major. For student preparation, we examine students' high-school calculus experience. For perceived pedagogical activities, we compare student responses to twelve items on the end-of-term survey. Students were asked to report on a scale from 1 (not at all) to 6 (very frequently) on the frequency of their instructor doing the following: show how to work specific problems, prepare extra material to help students understand calculus concepts or procedures, hold a whole-class discussion, have students give presentations, require you to explain your thinking on exams, lecture, require you to explain your thinking on your homework, ask questions, ask students to explain their thinking, have students work with one another, have students work individually on problems or tasks, and assign sections in your textbook for you to read before coming to class.

After identifying which reported pedagogical activities are univariately related to end-of-term calculus intention, we explore whether these relationships hold when controlling for class as a random effect. That is, we determine if the variance occurs across class or within classes. To do this, we conduct a number of multivariable logistic regressions to predict end-of-term calculus intention, nesting within classes and controlling for student demographics and preparation. Thus, we investigate how reporting low levels of discussion, for example, within a class predicts a student's end of term Calculus II intention, while controlling for gender, major, parents'/ guardians' education level, and high school calculus experience. We use SPSS version 20 to conduct all analyses. In the following sections we first present the results of the descriptive and univariate analyses, and then the results for the multivariable analyses. We conclude with a discussion interpreting these results.

4 Descriptive and Univariate Analyses

4.1 Instructor and Student Reports

Student reports of instructional practices represent their perceptions of what occurred during or in relation to class. Students' perceptions may be influenced by a number of factors, such as their personal feelings about the instructor, teaching and learning, their own course performance, the content of the course, etc. Nevertheless, student surveys have been shown to be valid and reliable representations of instruction. For example, a recent report from the Measures of

[1] The higher proportion of Converters in the restricted dataset is due to the removal of a disproportionate number of Culminaters from the two institutions excluded from the study.

Effective Teaching (MET) Project of the Bill and Melinda Gates Foundation used student responses to a survey regarding perception of instructor practices as the primary method for evaluating teacher effectiveness (Ferguson 2012). Findings indicated that student perception surveys are valid, reliable, and stable over time at the classroom level, and produce more consistent results than classroom observations or achievement gain measures when used to evaluate teacher effectiveness (Mihaly, McCaffrey, Staiger, and Lockwood 2013).

In order to understand the validity and reliability of student reports of classroom activities in our data set, we compared student reports to instructor reports of the frequency of twelve pedagogical activities during class. Specifically, we conduct paired samples t-tests for each of the twelve student-teacher reports. Table 2 shows the results of this analysis. Many of the differences are statistically significant, though clinically small in magnitude. All differences between student mean and instructor mean are between 0.001 and 0.71 in magnitude, indicating overall a large amount of agreement. Instructors report eight of the activities occurring with higher frequency than students, with "asking questions" and "requiring students to explain their thinking on their homework" the most over reported when compared to students, with disagreements of 0.71 and 0.37 respectively. The items for which students reported occurring more frequently than instructors include "having students work individually on problems or tasks" and "preparing extra material to help students understand calculus concepts or procedures", with disagreements of 0.57 and 0.06 respectively.

We take away two main points from this analysis: first, there is a great deal of overall agreement between student and instructor reports of the frequencies of specific pedagogical activities; second, where there is disagreement, it seems instructors over report activities that may be deemed as "innovative", such as asking questions and having students explain their thinking, while they underreport more "traditional" activities, such as having students work individually on problems during class.

Table 2 Mean comparison of student and instructor reports on twelve pedagogical activities

How often did your instructor (you):		**Mean**	**Std. Dev.**	**Std. Error Mean**
Activities that instructors report occurring more frequently than students				
ask questions?***	Student	4.59	1.22	.03
	Instructor	5.30	1.04	.02
require you to explain your thinking on your homework?***	Student	3.27	1.75	.04
	Instructor	3.65	1.72	.04
have students work with one another?***	Student	2.86	1.76	.04
	Instructor	3.20	1.79	.04
ask students to explain their thinking?***	Student	3.61	1.61	.04
	Instructor	3.95	1.53	.03
hold a whole-class discussion?***	Student	3.18	1.81	.04
	Instructor	3.41	1.74	.04
show how to work specific problems?***	Student	4.97	1.10	.02
	Instructor	5.16	1.10	.02
require you to explain your thinking on exams?***	Student	3.95	1.69	.04
	Instructor	4.13	1.58	.04
assign sections in your textbook for you	Student	3.44	1.96	.04

to read before coming to class?**	Instructor	3.54	2.05	.05
lecture?**	Student	5.25	1.11	.03
	Instructor	5.31	1.10	.03
have students give presentations?	Student	1.56	1.16	.03
	Instructor	1.56	.97	.02
Activities that students report occurring more frequently than instructors				
have students work individually on problems or tasks?***	Student	3.64	1.72	.04
	Instructor	3.07	1.62	.04
prepare extra material to help students understand calculus concepts or procedures?	Student	3.95	1.57	.04
	Instructor	3.89	1.57	.04

Note. * = $p \leq .10$, ** = $p \leq .05$, *** = $p \leq .001$; N is between 1,990 and 2,014 depending on the item.

4.2 STEM intention and other variables

Rasmussen and Ellis (2013) determined that a number of variables appear to be correlated with persistence among STEM intending students. In this study we expand on these results in two ways: First, we open up the analysis to initially non-STEM intending students to see the relationship between their experience in Calculus I and their end of term STEM intention. Second, we use these relationships to inform a predictive model of end of term STEM intention. In this section, we look at the relationships between end of term STEM intention and a number of student variables, including demographics, preparation, and perceived pedagogy. After looking at the individual relationships between these variables and end of term STEM intention, we look at the predictive power of each of the perceived pedagogical activities while controlling for the group-effect of course enrollment as well as demographic and background characteristics. In all univariate and multivariable analyses, STEM intending and non-STEM intending students are treated as two separate study populations. In other words, comparisons are between Persisters and Switchers, on the one hand, and Culminaters and Converters, on the other hand.

4.2.1 Student Demographics

We explore a number of demographic variables in relation to end of term STEM intention, including gender, race/ethnicity, parent or guardians' education level as a measure of socio-economic status (SES), and intended majors. As shown in Table 3a, among initially STEM intending students gender is significantly correlated with switching STEM intention. Among STEM intending males, 11.1% change their intention at the end of the term while 20.1% of females do. Race/ethnicity, on the other hand, is not significantly related to end of term STEM intention among initially STEM intending students, although the switching percentage of Asians, Pacific Islanders, and American Indians or Alaska Natives are disproportionately high.

As shown in Table 3b, among initially non-STEM intending students, gender is not significantly related to end of term STEM intention, although females are converting to be STEM intending at disproportionately lower rates than males. Race/ethnicity is significantly related to end of term STEM intention among initially non-STEM intending students, with Black students Converting at disproportionately *high* rates and Hispanic students Converting at disproportionately *low* rates.

Table 3a Demographic characteristics of initially STEM intending students by end-of-term Calculus II intention

	Gender***		Race/ Ethnicity					
	Male	**Female**	**White**	**Black**	**Asian**	**Pacific Islander**	**American Indian or Alaskan Native**	**Hispanic Origin**
Persisters	853	579	1033	41	158	9	18	131
	88.9%	79.9%	85.5%	85.4%	81.9%	75%	75%	86.2%
Switchers	106	146	175	7	35	3	6	21
	11.1%	20.1%	14.5%	14.6%	18.1%	25%	25%	13.8%

Note. * = p ≤ .10, ** = p ≤ .05, *** = p ≤ .001

Table 3b Demographic characteristics of initially non-STEM intending students by end-of-term Calculus II intention

	Gender		Race/ Ethnicity**					
	Male	**Female**	**White**	**Black**	**Asian**	**Pacific Islander**	**American Indian or Alaskan Native**	**Hispanic Origin**
Culminaters	108	180	209	8	28	0	3	28
	83.1%	90%	87.8%	72.7%	82.4%	0%	75%	93.3%
Converters	22	20	29	3	6	1	1	2
	16.9%	10%	12.2%	27.3%	17.6%	100%	25%	6.7%

Note. * = p ≤ .10, ** = p ≤ .05, *** = p ≤ .001

In order to account for socio-economic status as a demographic factor, we use the male and female parent's or guardian's highest level of education. As shown in Table 4a, among initially STEM intending students, there was no significant relationship between parents'/guardians' education level and calculus persistence, however students with either parent holding a graduate degree tended to be *more* likely to be a switcher than students with either parent having completed no or some college.

Similarly, there was no significant relation between this measure of SES and end of term STEM intention among initially non-STEM intending students, as shown in Table 4b. However, students whose male parent or guardian completed no college tended to be *more* likely to Convert to be STEM intending and students whose female parent or guardian completed no college tended to be *less* likely to Convert.

Table 4a Parents' highest education for initially STEM intending students by end-of-term Calculus II intention

	Male Parent of Guardian			**Female Parent of Guardian**		
	No College	**Some College**	**Graduate School**	**No College**	**Some College**	**Graduate School**
Persisters	327	695	410	284	833	315
	84.9%	86.1%	83.3%	85.8%	85.5%	83.1%
Switcher	58	112	82	47	141	64
	15.1%	13.9%	16.7%	14.2%	14.5%	16.9%

Note. * = p ≤ .10, ** = p ≤ .05, *** = p ≤ .001

Table 4b Parents' highest education for initially non-STEM intending students by end-of-term Calculus II intention

	Male Parent of Guardian			**Female Parent of Guardian**		
	No College	**Some College**	**Graduate School**	**No College**	**Some College**	**Graduate School**
Culminaters	52	146	90	55	171	62
	80%	90.7%	86.5%	90.2%	86.4%	87.3%
Converters	13	15	14	6	27	9
	20%	9.3%	13.5%	9.8%	13.6%	12.7%

Note. * = p ≤ .10, ** = p ≤ .05, *** = p ≤ .001

The last available background variable we consider as being potentially related to end of term STEM intention is intending career. Students were able to choose from one of 16 majors, including both STEM and non-STEM related majors. We present the percentages of students from the most populated majors as well as majors of specific interest, such as math majors and teachers. For both initially STEM intending and non-STEM intending students, career choice is significantly related to end of term STEM intention. Among initially STEM intending students, Engineers and Math majors are disproportionately unlikely to become switchers whereas Pre-Medical students, Business majors, and Undecided students are the most likely to become switchers, as shown in Table 5a. Among non-STEM intending students, students with majors in the Life Sciences[2] and Undecided majors are the most likely to switch *into* STEM intention, while students in non-Pre Medical health professional and non-math and science teachers are the least likely to switch into STEM intention, as shown in Table 5b.

These results together highlight a number of issues. First, students who enter Calculus I undecided in their major are, unsurprisingly, the most flexible in changing their STEM intentions both *into* STEM intention and *out* of STEM intention. These students represent an important source of potential STEM majors, and so increasing these students' end of term STEM intention is one important way to increase the number of STEM majors. Second, pre-Medical students and Business majors appear especially sensitive in their STEM intention, likely due to the multiple specialties within these fields with various STEM requirements. For instance, many Economics majors are required to take Calculus II, and thus

[2] Life science majors should, nominally, be identified as STEM intending. However, these majors do not require Calculus II and thus are excluded from our identification.

Business majors who initially intend to take Calculus II but later switch might be opting for a non-STEM oriented Business specialty, such as Marketing or Accounting. These students, as well as the pre-medical switchers, represent another large group of potential STEM majors that have already expressed interest towards these fields.

Table 5a Intended majors of initially STEM intending students by end-of-term Calculus II intention.***

	Medical	Engineer	Comp Sci	Math	Science /Math teacher	Business	Undecided
Persisters	258	603	85	29	64	51	101
	78.7%	94.5%	89.5%	93.5%	87.7%	67.1%	75.4%
Switchers	70	35	10	2	9	25	33
	21.3%	5.5%	10.5%	6.5%	12.3%	32.9%	24.6%

Note. * = $p \leq .10$, ** = $p \leq .05$, *** = $p \leq .001$

Table 5b Intended majors of initially non-STEM intending students by end-of-term Calculus II intention.**

	Medical	Other health professional	Life Science	Other teacher	Business	Undecided
Culminaters	98	19	15	11	34	43
	88.3%	95%	78.9%	100%	87.2%	84.3%
Converters	13	1	4	0	5	8
	11.7%	5%	21.1%	0%	12.8%	15.7%

Note. * = $p \leq .10$, ** = $p \leq .05$, *** = $p \leq .001$

4.2.2 Student Preparation

To examine student preparation we use high-school Calculus experience. In the US, there are a variety of types of Calculus that students may take. The College Board's Advanced Placement (AP) Calculus Program allows high school students to begin university-level work in calculus. There are two levels of AP Calculus: AB, which covers the content equivalent to one semester of college level Calculus I; and BC, which covers all of the topics included in AP Calculus AB, as well as series, parametric equations, advanced integration techniques, and differential equations for logistic growth. Each course is accompanied by an optional AP exam, which is scored from 1 to 5. Typically, if the AB exam is passed with a score of 3 or higher the student receives credit for Calculus I in college, depending on the institution. Similarly, passing the BC exam with a 3 or higher typically results in credit of both Calculus I and Calculus II in college. We group students into four categories regarding high school calculus experience: no high school calculus experience, non-AP calculus course, AP Calculus AB, and AP Calculus BC.

Surprisingly, univariate analyses show no significant relationships between high school Calculus experience and STEM intention, among both initially STEM intending and non-STEM intending students. However, as shown in Table 6a, students who took either no Calculus in high school or AP Calculus BC are least likely to switch out of STEM intention and students who took non-AP calculus in high school are the most likely to switch. Though this result is statistically insignificant, this trend indicates that students who take non-AP Calculus are more likely to switch out of STEM intention than students who had never taken calculus in high school.

Among non-STEM intending students, there is a linear trend between higher levels of high school Calculus experience and switching *in* to STEM intention, as shown in Table 6b. Student who took no high school Calculus were least likely to switch in to STEM intention while students who took AP Calculus BC are most likely to switch in. This trend indicates that mathematical experience is related to end of term STEM intention among students who were not originally STEM intending.

Table 6a High school Calculus experience of STEM intending students by end-of-term Calculus II intention.

	None	**Non-AP Calculus**	**AP Calculus AB**	**AP Calculus BC**
Persisters	547	244	521	120
	85.6%	83.6%	84.7%	87%
Switcher	92	48	94	18
	14.4%	16.4%	15.3%	13%

Note. * = p ≤ .10, ** = p ≤ .05, *** = p ≤ .001

Table 6b High school Calculus experience of non-STEM intending students by end-of-term Calculus II intention.

	None	**Non-AP Calculus**	**AP Calculus AB**	**AP Calculus BC**
Culminaters	126	63	83	16
	88.7%	87.5%	86.5%	80%
Converters	16	9	13	4
	11.3%	12.5%	13.5%	20%

Note. * = p ≤ .10, ** = p ≤ .05, *** = p ≤ .001

4.2.3 Reported Pedagogy

To examine the univariate relationships between reported pedagogical activities and end of term intention to take Calculus II, we first compare the percentages of Persisters and Switchers who reported low (report of 1, 2, or 3) frequencies of the 12 pedagogical activities. As shown in Table 7a, there are a number of reported pedagogical activities for which a significantly disproportionately high number of Switchers reported low levels. These activities include: showing students how to work specific problems, lecturing, preparing extra material to help students understand calculus concepts or procedures, requiring students to explain their thinking on exams, and holding a whole class discussion. For instance, 15.9% of Switchers reported their instructor showed them how to work specific problems at low frequencies, whereas only 9.1% of Persisters reported this occurring at low frequencies. This indicates a relationship between reporting these activities occurring at low frequencies and changing the intention to take Calculus II, and therefore STEM intention. A number of activities that Rasmussen and Ellis (2013) determined to be related to STEM persistence no longer show statistically significant trends, such as having students work with one another in class and asking students to explain their thinking. This is likely due to the removal of a large number of students (N>500) coming from classes that reported high levels of this activity.

This analysis indicates that reports of low levels of specific activities are individually related to STEM persistence. This could indicate one of two things: either Switchers and Persisters are in classes with differing frequencies of the above activities, or Switchers and Persisters are in the same classes but perceiving that these activities happen at differing frequencies. In the following analysis, we investigate these possibilities by determining the relationships between low reports of these activities *within classes*, while controlling for student demographics and preparation.

Table 7a Proportion of reports of low frequency for each pedagogical activity by end-of term Calculus II intention among STEM intending students

How frequently did your instructor:	Persisters with LOW reports	Switchers with LOW reports
hold a whole-class discussion?**	785	156
	54.8%	61.9%
prepare extra material to help students understand calculus concepts or procedures?**	505	106
	35.3%	42.1%
require you to explain your thinking on exams?*	505	103
	35.3%	40.9%
show how to work specific problems?***	130	40
	9.1%	15.9%
lecture?*	113	28
	7.9%	11.1%
have students give presentations?	1295	235
	90.4%	93.3%
have students work with one another?	899	156
	62.8%	61.9%
require you to explain your thinking on your homework?	764	141
	53.4%	56%
assign sections in your textbook for you to read before coming to class?	755	124
	52.7%	49.2%
ask students to explain their thinking?	630	116
	44%	46%
have students work individually on problems or tasks?	611	108
	42.7%	42.9%
ask questions?	244	48
	17%	19%

Note. * = $p \leq .10$, ** = $p \leq .05$, *** = $p \leq .001$

As shown in Table 7b, we repeat this analysis for originally non-STEM intending students in order to answer the question: does perception of pedagogical activities affect a student's decision to switch *in* to the STEM pipeline (as indicated by taking Calculus II)? This analysis shows that the answer to this question is predominantly no, at least not to a significant level. The only activity for which there was a significant difference between the proportion of Converters and Culminaters that reported low frequencies was asking students to explain their thinking. For this activity, 57.1% of Converters reported this occurring at low frequencies, whereas 41.7% of Culminaters reported it occurring at low frequencies. Thus, among students who originally did not intend to take Calculus II, being in a class in which they were infrequently asked to explain their thinking is related to switching *into* intending to take Calculus II. This unexpected trend is repeated (albeit at sub-significant levels) among a number of pedagogical activities that are more often viewed as "innovative", including having students give presentations, holding a whole-class discussion, and having students work with one another. These results suggest that for non-STEM intending students, being in an innovative class may discourage students from switching into the STEM trajectory. However, we caution that the small number of students for which these analyses are conducted (N=42) lessens the generalizability of these results. In the following multivariable analysis, we look into the relationship between reporting low levels of being asked to explain your thinking during class and switching into STEM intention, controlling for student demographics and preparation.

Table 7b Proportion of reports of low frequency for each pedagogical activity by end-of term Calculus II intention among non-STEM intending students

How frequently did your instructor:	Culminaters with LOW reports	Converters with LOW reports
ask students to explain their thinking?*	120 41.7%	24 57.1%
have students give presentations?	258 89.6%	39 92.9%
hold a whole-class discussion?	167 58%	28 66.7%
have students work with one another?	162 56.2%	28 66.7%
require you to explain your thinking on your homework?	147 51%	24 57.1%
have students work individually on problems or tasks?	130 45.1%	20 47.6%
assign sections in your textbook for you to read before coming to class?	128 44.4%	19 45.2%
require you to explain your thinking on exams?	94 32.6%	16 38.1%
prepare extra material to help students understand calculus concepts or procedures?	105 36.5%	11 26.2%
ask questions?	43 14.9%	6 14.3%
show how to work specific problems?	32 11.1%	3 7.1%
lecture?	20 6.9%	3 7.1%

Note. * = $p \leq .10$, ** = $p \leq .05$, *** = $p \leq .001$

In the previous section we explored the relationships between calculus intention and student demographics, preparation, and perceived pedagogical activities. It is clear that some variables are related to end of term calculus intention, such as gender and career choice, but many other variables exhibit trends with calculus intention but do not show statistical significance. In the following section, we develop models of calculus intention in relation to the five reported pedagogical activities that were significantly related to calculus intention among initially STEM intending students, and the one reported activity that was significantly related to calculus intention among initially non-STEM intending students. In each model we control for class as a random effect, as well as for each of the student demographic and preparation variables explored above.

5 Multivariable Analyses

Results from the univariate analyses suggest that certain reported pedagogical activities appear to be associated with the decision to switch out of the calculus sequence (among STEM intending students) or decide to take more calculus than originally planned (among non-STEM intending students). These analyses in turn open up the question of whether differences in calculus persistence are (a) related to differences between classes (e.g. perhaps switchers are disproportionately located in classrooms with low levels of whole-class discussion) or (b) related to differences in how students are experiencing classroom pedagogy within the same class (e.g. perhaps switchers report or experience relatively lower frequencies of whole-class discussion than do their persisting classmates). To address the latter possibility, analyses using multivariable binary logistic regressions, nesting students within classes, were used to determine how student perception of pedagogy *within a class* predicts students' end-of-term intention to take Calculus II. We report the results of these models for each of the two study populations, STEM intending and non-STEM intending students, respectively.

5.1 STEM intending students

We first report the results of these analyses for originally STEM intending students, as determined by their original intention to take Calculus II. The univariate analyses showed five of the twelve reported pedagogical activities to be correlated with end-of-term intention to take Calculus II: showing how to work specific problems, preparing extra material to help students understand calculus concepts or procedures, hold a whole-class discussion, require you to explain your thinking on exams, and lecture (see Table 7a). In the multivariable analyses, we investigate if these relationships were due to students being in classes with differing frequencies of these activities, or if instead the relationships are due to differing experiences among students within the same class.

We constructed five different multivariable logistic regression models to determine the adjusted odds of switching out of the calculus sequence associated with reporting a relatively low frequencies of each of these five pedagogical activities respectively. Each model was adjusted for demographic and background characteristics, including student major, gender, parent/guardian education level, and prior high-school calculus experience. Additionally, each model was adjusted for the group effect of the specific calculus course in which each study participant was enrolled by including this variable as a random (i.e. nested) effect. Table 8 displays the odds ratios and 90% confidence intervals for each of the five pedagogical activities. References categories are reporting relatively high frequency of the given activity and persisting in calculus so that each odds ratio gives the adjusted odds of switching out of the calculus sequence given reported low frequency of the pedagogical activity.

Table 8 Adjusted odds of switching out of the calculus sequence associated with reporting low frequencies of pedagogical activity

Pedagogical activity	Odds Ratio	90% Confidence Interval	
show how to work specific problems?**	1.91	1.24	2.93
prepare extra material to help students understand calculus concepts or procedures?**	1.43	1.11	1.84
hold a whole-class discussion?**	1.41	1.04	1.92
require you to explain your thinking on exams?**	1.35	1.05	1.75
lecture?	1.27	0.85	1.91

Note. * = p ≤ .10, ** = p ≤ .05, *** = p ≤ .001

Of the five pedagogical activities, all but lecture remain significantly related to end of term calculus persistence, once we control for class and other demographic and background variables. Specifically, increased odds of switching out of calculus were associated with reporting that the teacher infrequently (a) showed students how to work specific problems (OR = 1.91, 90% CI 1.24, 2.93), (b) prepared extra material to help students understand calculus concepts or procedures (OR = 1.43, 90% CI 1.11, 1.84), (c) held a whole-class discussion (OR = 1.41, 95% CI 1.04, 1.92), and (d) required student to explain thinking on exams (OR = 1.35, 90% CI 1.05, 1.75). In other words, even when controlling for the group effect of class, reports of low frequencies of these four pedagogical activities remain significantly associated with switching out of calculus, suggesting that there are significant differences in how Switchers and Persisters are experiencing the same course. Conversely, the association between reporting low frequency of lecture and calculus persistence identified in the univariate analysis is no longer present when controlling for the group effect of class, suggesting that this association is not due to differences in how Switchers and Persisters are experiencing the same class but rather due to differential enrollment in courses with relatively different amounts of lecture. We explore potential interpretations and implications of these findings in the discussion section.

5.2 Originally non-STEM intending students

The univariate analyses showed only one of the twelve reported pedagogical activities to be correlated with end-of-term intention to take Calculus II among initially non-STEM intending students: explaining thinking during class. In the multivariable analyses, we investigate if this relationship is due to students being in classes with differing frequencies of this activity, or if instead the relationship is due to differing experiences among students within the same class.

We constructed a multivariable logistic regression model to determine the adjusted odds of converting in to the calculus sequence associated with reporting a relatively low frequency of explaining thinking during class. This model was adjusted for demographic and background characteristics, including student major, gender, parent/guardian education level, and prior high-school calculus experience. Additionally, this model was adjusted for the group effect of the specific calculus course in which each study participant was enrolled by including this variable as a random (i.e. nested) effect.

The model shows that explaining thinking during class remains significantly related to end of term calculus persistence among initially non-STEM intending students, once we control for class and other demographic and background variables. Specifically, increased odds of converting in to calculus were associated with reporting that the teacher infrequently required students to explain their thinking during class (OR = 1.95, 90% CI 0.94, 4.03). In other words, even when controlling for the group effect of class, reporting low frequencies of being required to explain thinking remains significantly associated with switching in to calculus, suggesting that there are significant differences in how Converters and Culminaters are experiencing the same course with regards to the amount they are asked to explain their thinking during class. We explore this finding further in the discussion section.

6 Discussion

This analysis has been motivated by previous findings that among initially STEM intending students, as indicated by their intention to take Calculus II, students who continue to be STEM intending at the end of Calculus I report being more engaged during class than students who switch their STEM intention. We wondered if this was due to students being in different classes or, instead, experiencing the same classes differently. In order to answer this question, we first explored a number of variables related to student demographics and preparation to understand the profiles of the four types of students involved in this study: Persister – students who began and finished Calculus I intending to take Calculus II; Switcher – students who began intending to take Calculus II but who no longer did by the end of Calculus I; Culminaters – students who began and ended Calculus I not intending to take Calculus II; and Converters – students who began Calculus I not intending to take Calculus II but did by the end of Calculus I.

We then investigated the univariate relationships between reports of pedagogical activities among these four types of students. Among initially STEM intending students, five pedagogical activities were significantly related to end-of-term calculus intention: showing how to work specific problems, preparing extra material to help students understand calculus concepts or procedures, hold a whole-class discussion, require you to explain your thinking on exams, and lecture. Among initially non-STEM intending students, only one pedagogical activity was significantly related to end-of-term calculus intention: being required to explain thinking during class.

We then further investigated these relationships within the class, answering our original question of whether or not these differences remained once we controlled for class as a random effect. For initially STEM intending students, we conducted 5 different multivariable logistic regression models for each of the pedagogical activities that was shown to be univariately associated with end-of-term calculus intention. For initially non-STEM intending students, we conducted one multivariable logistic regression model for the one pedagogical activity that was significantly univariately associated with end-of-term calculus intention. For each of these six models we controlled for demographic and background characteristics, including student major, gender, parent/guardian education level, and prior high-school calculus experience. Additionally, each model was adjusted for the group effect of the specific calculus course in which each study participant was enrolled by including this variable as a random (i.e. nested) effect.

Among initially STEM intending students, each of the pedagogical activities except for lecture remained significantly related to end-of-term calculus intention. Among initially non-STEM intending students, requiring students to explain their thinking during class remained significantly related to end-of-term calculus intention.

The analyses show that, even within a single class, there are significant differences between how Switchers and Persisters report the frequency of being shown how to work specific problems during class. Thus, in answer to our driving question of whether or not Switchers and Persisters were in different classes or the same classes and experiencing them differently, we see that students within the same class experience their instructor showing them how to work specific problems significantly differently. This result indicates that one component of persisting in calculus is experiencing that one's instructor is showing him or her how to solve the problems that her or she will be asked to solve. Why would students within the same class experience this occurring at different frequencies? It is possible that although a student may see the instructor showing students how to do specific problems, the student doesn't perceive the instructor showing him or her how to do specific problems. Thus, this student may feel that while other students are being given the tools to succeed, he or she is not. An alternate explanation may be that Switchers less often connect what the instructor is doing in class to what they are being asked to do on homework or exams, and thus are less likely to perceive what the instructor does in class as showing how to solve problems that will arise on homework or exams.

Similarly, there are significant differences between how Switchers and Persisters report the frequency of their instructors preparing extra material for the purpose of helping students to understand, with Switchers reporting this occurring less frequently than Persisters within the same classes. This result indicates that experiencing that your instructor is preparing extra materials so that you can understand calculus is a component of persistence in calculus among STEM intending students. The experience that your instructor is preparing extra materials so that you will understand calculus may have less to do with the materials themselves and more to do with the perception that the instructor is spending extra time and effort for the purposes of student learning. Students who perceive that their instructor prepares extra materials for them infrequently may feel that their instructors care about their success less than students who perceive their instructors preparing extra materials for them frequently. Conversely, this result may indicate that students who perceive their instructor preparing extra materials for the purpose of their understanding of calculus at a higher frequency may see those materials as more helpful for their own understanding of calculus.

Within a class, the analyses show that students who perceive their instructor holding a whole-class discussion infrequently are more likely to be a Switcher versus a Persister, while controlling for course enrollment and other background variables. This result makes clear that Switchers are not in classes with low levels of whole-class discussion while Persisters are in classes with high levels. Instead, Persisters experience high levels of whole class discussion and Switchers experience low levels of discussion, even within the same class. This result raises a number of questions. First, do students know what a whole-class discussion is, or is this an education-researcher construct that lacks meaning for students? It is likely that the term holds different meaning for researchers than for students, however there is a clear and statistically significant trend that Persisters report whole-class discussion occurring more frequently than Switchers within the same class.

The second question is why? From an instructor's perspective, they may be holding a whole-class discussion when they ask a variety of students to answer questions, to ask each other questions, and to explain their thinking. From the perspective of the students involved in that discussion, the instructor may be holding a whole-class discussion. But for the students that are not being explicitly included in the discussion, they may not perceive a *whole-class* discussion. In classes greater than 10 students it would be very unlikely to have a true *whole-class* discussion, and thus only some students will be explicitly involved in the discussion. Instructors likely engage the students that are easiest to engage with during discussions. Wagner, Speer, and Rossa (2007) provide an account of one instructor's (Rossa) experience implementing an Inquiry-Oriented curriculum in a differential equations course which involves facilitating whole-class discussion as well as group work and other "innovative" practices. The authors highlight the difficulties and questions that Rossa had during this process, including how to productively draw on students' ideas during whole class discussion, even when the ideas are incorrect, and how to "cover" all of the material in the course when so much time is spent on whole-class discussions. One way to solve these problems is to engage the students who will answer the questions and explain their thinking correctly and quickly. Our analyses suggest that this solution may be detrimental to some students' persistence in calculus. An implication of this result for instructors is to be more uniform in engaging students during class discussions. It is likely that the students who benefit from whole-class discussion are the students involved in whole-class discussions, and thus students need to be more equitably involved in whole-class discussions.

The final pedagogical activity that is significantly linked to persistence in calculus among initially STEM intending students is the report that students are frequently required to explain their thinking on exams. Thus, the perception that your instructor is requiring you to explain your thinking on exams infrequently is predictive of switching your intention to take Calculus II. Again, we ask why? Because all students in an individual class take the same exams, it is unlikely that students within the same class are inequitably being asked to explain their thinking on the exams. Instead, there is a relationship between perceiving that you are asked to explain you thinking on exams and intending to take Calculus II. One possible explanation for this result is that students who feel that they are being assessed on their ability to explain their thinking on calculus problems feel more prepared to go onto Calculus II.

The only pedagogical activity that was significantly related to calculus persistence univariately but not multivariately when controlling for class was lecture. This result indicates that Switchers are disproportionately in classes with low lecture, and thus likely look very different from students' previous mathematical classes from high school. This may be indicative of students' discomfort with class environments that deviate drastically from their expectations.

Among initially non-STEM intending students, only one pedagogical activity was associated with end-of-term calculus intention: being required to explain thinking during class. This association was present in both univariate and multivariable analyses. Thus, for students who did not initially intend to take Calculus II, perceiving that they were required to explain their thinking infrequently during class was related to converting *in* to STEM intention. In other words, perceiving that they were required to explain their thinking is inversely related to switching into STEM intention. This unexpected result raises questions about these students' beliefs about mathematics and what it means to learn mathematics. Do Converters hold beliefs about mathematics that are challenged when they are asked to explain their thinking? By not being asked to explain their thinking in Calculus I, do Converters shift their expectations about what it will take to succeed in Calculus II? In future work we will explore the relationships between students' beliefs about mathematics and their intention to take Calculus II, and thus pursue a STEM field.

Taken together, these results have significant implications for the classroom environment. First, for initially STEM intending students, who make up the majority of the mainstream Calculus I class in the US, a classroom with infrequent lecture may present a violation of student expectations about mathematics instruction in ways that ultimately bear on their persistence in the calculus sequence. Further research is needed to explore how experiences in non-lecture style calculus classrooms are influencing decisions of STEM intending students to pursue more calculus. Moreover, when more innovative pedagogical activities, such as whole-class discussion, are implemented, student persistence in calculus depends on their equitable implementation.

7 References

Carnevale, A. P., Smith, N., & Melton, M. (2011). STEM: Science, technology, engineering, mathematics. Georgetown University, Center on Education and the Workforce. Retrieved from http://www9.georgetown.edu/grad/gppi/hpi/cew/pdfs/stem-complete.pdf

Ferguson, R. (2012). Can Student Surveys Measure Teaching Quality?. *Phi Delta Kappan* 94.3, 24-28.

Hurtado, S., Eagan, M. K., & Chang, M. (2010). Degrees of success: Bachelor's degree completion rates among initial STEM majors. Retrieved from http://www.heri.ucla.edu/nih/downloads/2010%20%20Hurtado,%20Eagan,%20Chang%20-%20Degrees%20of%20Success.pdf

Kazemi, E. & Stipek, D. (2001). Promoting conceptual thinking in four upper-elementary mathematics classrooms. *The Elementary School Journal,* 102(1), 59-80.

Kuh, G., Cruce, T., Shoup, R., Kinzie, J., and Gonyea, R. (2008). Unmasking the effects of student engagement on first-year college grades and persistence. *The Journal of Higher Education,* 79 (5), 540-563.

Lodico, M.G., Spaulding, D.T., & Voegtle, K.H. (2010). *Methods in Educational Research: From Theory to Practice* (2nd ed.). San Francisco: Jossey-Bass.

Lutzer, D.J., Rodi, S.B., Kirkman, E.E., & Maxwell, J.W. (2007), *Statistical Abstract of Undergraduate Programs in the Mathematical Sciences in the United States*. Conference Board of the Mathematical Sciences. American Mathematical Society, Providence, RI.

Mihaly, K., McCaffrey, D. F., Staiger, D. O., & Lockwood, J. R. (2013). A Composite Estimator of Effective Teaching. Retrieved from http://www.nbexcellence.org/cms_files/resources/Jan%202013%20%20A%20Composite%20Estimator%20of%20Effective%20Teaching%20Research%20Paper.pdf

President's Council of Advisors on Science and Technology (PCAST) (2012). *Engage to excel: Producing one million additional college graduates with Degrees in Science, Technology, Engineering, and Mathematics*. Washington, DC: The White House.

Rasmussen, C. & Ellis., J. (2013). Who is switching out of calculus and why? *Proceedings of the 37th conference of the international group for the psychology of mathematics education.*

Seymour, E. & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduate leave the sciences*. Boulder, CO: Westview Press.

Szafran, R. (2012). *Answering Questions with Statistics*. Los Angeles, CA: Sage Publications.

Tinto, V. (1975). Dropout from higher education: A theoretical synthesis of recent research. *Review of Educational Research,* 45(1), 89-125.

Tinto, V. (2004). Linking learning and leaving. In J. M. Braxton (Ed.) *Reworking the student departure puzzle*. Nashville, TN: Vanderbilt University Press.

Wagner, J. F., Speer, N. M., & Rossa, B. (2007). Beyond mathematical content knowledge: A mathematician's knowledge needed for teaching an inquiry oriented differential equations course. Journal of Mathematical Behavior, 26, 247–266.