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ORIGINAL ARTICLE

Student perceptions of pedagogy and associated persistence in calculus

Jessica Ellis · Molly L. Kelton · Chris Rasmussen

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Abstract There is a clear need to increase student persistence in Science, Technology, Engineering, or Mathematics (STEM). Prior analyses have shown that students who change their Calculus II intention (a proxy for STEM intention) report being less engaged during class than students who persist onto Calculus II. This led us to ask: Are these students in different classes, or are they in the same classes but experiencing them differently? We present descriptive and univariate analyses of the relationship of calculus persistence to student demographics, background characteristics, and reported instruction for 1,684 STEM intending students and 330 non-STEM intending students enrolled in introductory calculus in Fall 2010 in the United States. We then 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 is associated with calculus persistence. These analyses show that different student perceptions of the frequency of a number of pedagogical activities, and thus different ways of experiencing the same class, are related to students' decision to continue studying calculus. Specifically, among initially STEM intending students, there was a relationship between persistence and the perceived frequency of the instructor showing students how to work specific problems, preparing extra material to help students understand calculus concepts or procedures, holding a whole-class discussion, and requiring students to explain their thinking on exams. Among initially non-STEM intending students, there was a relationship between persistence and the perceived frequency of being required to explain thinking during class.

J. Ellis (✉)
Colorado State University, Fort Collins, USA
e-mail: jess.ellis84@gmail.com

M. L. Kelton
University of California, San Diego, USA

M. L. Kelton · C. Rasmussen
San Diego State University, San Diego, USA

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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. Typically, over half of Calculus I students also took a calculus course in secondary school, which usually focuses on techniques of differentiation and integration. In comparison, a post-secondary calculus course is usually more rigorous in its treatment of concepts (including limits, graphical interpretations, definitions, etc.) and applications. Proofs, however, are typically not part of Calculus I.

In the US and elsewhere, first year university mathematics courses often function as a filter, preventing large numbers of students from pursuing a career in science, technology, engineering or mathematics (STEM) (Steen 1988; Wake 2011). In the United States first year students who are interested in pursuing a STEM field typically enroll in calculus. In many European countries, students who elect to pursue a STEM degree in post-compulsory education (onto college or university) typically study abstract algebra or proof-based calculus (Wake 2011).

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 in the US remains constant at around 30 % nationwide (Carnevale, Smith, and Melton 2011; Hurtado, Eagan, and Chang 2010). This problem is not unique to the US. In a study comparing the state of tertiary STEM education in Sweden, the UK, the US, and the Netherlands, van Langen and Dekkers (2005) determined that interest in STEM degree courses at the undergraduate level is a shared problematic issue "owing to a general declining interest, an under-representation of girls and women, acute shortfalls on the labour market and high economic ambitions" (p. 336). 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 and that a 10 % increase in the number of STEM majors would go far to meet this need.

Instructional experience in these first year mathematics courses is a major factor contributing to a student's decision either to continue or discontinue pursuing a STEM degree (Hutcheson, Pampaka, and Williams 2011; Pampaka, Williams, Hutcheson, Davis, and Wake 2012; Seymour and Hewitt 1997). For instance, Pampaka et al. (2012) found that students' declining disposition to study non-compulsory mathematics is intensified by "transmissionist" pedagogy. Similarly, Seymour and Hewitt (1997) found students in the US who leave STEM degrees often cite traditional and uninspiring instruction that emphasized rote memorization rather than conceptual understanding and applications as one of the major reasons for their departure. Because of this, a better understanding of the relationship between students' instructional experiences in these courses and students' decisions to continue taking additional mathematics courses is needed to improve student success in introductory mathematics and continued interest in STEM careers. Moreover, for those students whose culmination of their mathematical studies is Calculus I (or abstract algebra or proof-based calculus abroad), improved instruction might leave them with a better appreciation of mathematics, and potentially the desire to take more mathematics 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 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 2004). According to Tinto's framework (2004), 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 (Hutcheson, Pampaka, and Williams 2011; PCAST 2012; Rasmussen and Ellis 2013; Seymour 2006; Seymour and Hewitt 1997; Wolniak, Mayhew, and Engberg 2012). 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 as 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.

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 5,381 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 I. 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. When the authors compared reported instructional experiences of Switchers and Persisters, they found 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 they 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 1 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 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 2,014 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. 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 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. In a related study comparing student persistence among four instructors at one institution, Bagley (2013) found that our classifications of students were highly accurate when compared to their actual Calculus II enrollment.

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).

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. This provides us with a baseline understanding of how each of these variables is independently related to end-of-term calculus intention, as

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)	1,432 (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)[a]

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

well as the extent to which those relationships are statistically significant. Univariate analyses of student demographics and preparation provide baseline information about the composition of Persister and Switcher populations. Univariate analyses of reported pedagogical activities provide an initial indication of those pedagogical activities that are likely to predict end-of-term calculus intention, and are used to select those pedagogical activities that are further analyzed using multivariable models as described below. Parallel analyses were conducted for non-STEM intending students (i.e., Culminaters and Converters) but are discussed in less detail.

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:

1. show how to work specific problems;
2. prepare extra material to help students understand calculus concepts or procedures;
3. hold a whole-class discussion;
4. have students give presentations;
5. require you to explain your thinking on exams;
6. lecture;
7. require you to explain your thinking on your homework;
8. ask questions;
9. ask students to explain their thinking;
10. have students work with one another;
11. have students work individually on problems or tasks;
12. 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 construct statistical models that account for the fact that the data set consists of students nested within calculus courses, i.e., each student in the data set was only enrolled in a single course. Treating class as a random (i.e., nested) effect controls for variation *between* classes (i.e., controls for the fact that whole classes differ from one another) and examines how STEM persistence is associated with variation in perceived pedagogical activities *within* classes (i.e., examines how students in the same class perceive and report pedagogical activities differently as well as how those differences relate to STEM persistence). 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. In other words, while the univariate analyses indicate those pedagogical activities that are significantly associated with end-of-term STEM intention, the nested multivariable regression models allow us to (a) control for variation between classes so that any statistically significant associations are based on variations in how students *in the same class* perceive pedagogical activities and (b) assess whether and how those associations hold when controlling for the potential confounding effects of student demographics and preparation. 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 (Ferguson 2012; 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 conducted paired samples t tests for each of the twelve student–teacher reports. Table 2 shows the results of this analysis. While many of the differences are statistically significant, they are small in magnitude. That is, while pairwise t tests are able to detect differences in these means, the differences themselves are modest. Specifically, 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 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 some activities that may be deemed as "innovative", such as asking questions, having students explain their thinking, and having students work with one another, while they underreport having students work individually on problems during class, which may be considered a more "traditional" pedagogical activity.

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

How often did your instructor (you):	Mean	Instr. mean − stu. mean	Std. dev.	Std. error mean
Activities that instructors report occurring more frequently than students				
Ask questions?***				
Student	4.59	0.71	1.22	0.03
Instructor	5.30		1.04	0.02
Require you to explain your thinking on your homework?***				
Student	3.27	0.38	1.75	0.04
Instructor	3.65		1.72	0.04
Have students work with one another?***				
Student	2.86	0.34	1.76	0.04
Instructor	3.20		1.79	0.04
Ask students to explain their thinking?***				
Student	3.61	0.34	1.61	0.04
Instructor	3.95		1.53	0.03
Hold a whole-class discussion?***				
Student	3.18	0.23	1.81	0.04
Instructor	3.41		1.74	0.04
Show how to work specific problems?***				
Student	4.97	0.19	1.10	0.02
Instructor	5.16		1.10	0.02
Require you to explain your thinking on exams?***				
Student	3.95	0.18	1.69	0.04
Instructor	4.13		1.58	0.04
Assign sections in your textbook for you to read before coming to class?**				
Student	3.44	0.10	1.96	0.04
Instructor	3.54		2.05	0.05
Lecture?**				
Student	5.25	0.06	1.11	0.03
Instructor	5.31		1.10	0.03
Have students give presentations?				
Student	1.56	0.00	1.16	0.03
Instructor	1.56		0.97	0.02
Activities that students report occurring more frequently than instructors				
Have students work individually on problems or tasks?***				
Student	3.64	−0.57	1.72	0.04
Instructor	3.07		1.62	0.04
Prepare extra material to help students understand calculus concepts or procedures?				
Student	3.95	−0.06	1.57	0.04
Instructor	3.89		1.57	0.04

N is between 1,990 and 2,014

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.001$

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 include 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

Table 3 Demographic characteristics 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	1,033	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 %

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.001$

Persisters and Switchers, on the one hand, and Culminaters and Converters, on the other hand. Due to space limitations, we present detailed results for the STEM intending students and a summary of results for non-STEM intending students.

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 socioeconomic status (SES), and intended majors. In what follows, we discuss overall trends in the data regardless of whether they are statistically significant at the $p \leq 0.10$ level. When pairwise tests yielded a p value at or below 0.10 we consider the association to be statistically significant and refer to it as such.

As shown in Table 3, 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 percentages of Asians, Pacific Islanders, and American Indians or Alaska Natives are disproportionately high.

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.

In order to account for socioeconomic status as a demographic factor, we use the male and female parent's or guardian's highest level of education. As shown in Table 4, 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.

Table 4 Parents' highest education 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 %
Switchers					
58	112	82	47	141	64
15.1 %	13.9 %	16.7 %	14.2 %	14.5 %	16.9 %

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.001$

The last background variable we consider as being potentially related to end-of-term STEM intention is intended 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 5. Among non-STEM intending students, students with majors in the Life Sciences 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.

Table 5 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 %	1.5 %	6.5 %	12.3 %	32.9 %	24.6 %

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.001$

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 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.

4.2.2 *Student preparation*

To examine student preparation we use secondary 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 secondary 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 university 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 university. 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 secondary school calculus experience: no secondary school calculus experience, non-AP calculus course, AP Calculus AB, and AP Calculus BC.

Table 6 Secondary school calculus experience 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 %

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.001$

Surprisingly, univariate analyses show no significant relationships between secondary school calculus experience and Calculus II intention, among both initially STEM intending and non-STEM intending students. However, as shown in Table 6, students who took either no calculus in secondary school or AP Calculus BC are least likely to switch out of STEM intention and students who took non-AP calculus in secondary school are the most likely to switch out. 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 secondary school.

Among non-STEM intending students, there is a linear trend between higher levels of secondary school calculus experience and switching into STEM intention. Student who took no secondary school calculus were least likely to switch into 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.

4.2.3 *Reported pedagogy*

To examine the univariate relationships between reported pedagogical activities and end-of-term intention to take

Table 7 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 %	4.9 %
Show how to work specific problems?***	130	40
	9.1 %	15.9 %
Lecture?*	113	28
	7.9 %	11.1 %
Have students give presentations?	1,295	235
	9.4 %	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 %	56.0 %
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
	44.0 %	46.0 %
Have students work individually on problems or tasks?	611	108
	42.7 %	42.9 %
Ask questions?	244	48
	17.0 %	19.0 %

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.001$

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, a subset of the questions from Rasmussen and Ellis's study (2013). As shown in Table 7, 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 that 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, such as having students work with one another in class and asking students to explain their thinking, remain similarly associated with persistence though not at statistically significant levels due to the removal of a large number of students ($N > 500$) coming from classes that reported high levels of these activities.

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 and STEM persistence *within classes* by treating class as a nested variable in a logistic regression model. In addition, to minimize the potential confounding effects of demographic and background variables, we control for these in the regression models.

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 into 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.

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, while 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. The univariate analyses showed five of the twelve reported pedagogical activities to be correlated with end-of-term intention to take Calculus II (see Table 7). 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 frequency 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

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.001$

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 [odds ratio (OR) 1.91, 90 % confidence interval (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). This means, for example, that students who reported that the teacher infrequently showed students how to work specific problems were an estimated 1.91 times more likely to switch out of calculus than were their classmates who reported that their teacher engaged in this activity relatively frequently. 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 may be 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.

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. 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 into 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 Conclusion

6.1 Overview

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. Being engaged in university mathematics classes has been shown to make a difference in student learning as well as retention. For example, Kogan and Laursen (2013) found that the impact of active learning instructional strategies has a sizable and persistent positive effect on previously low achieving students with no harm done to other groups of students. Hutcheson, Pampaka, and Williams (2011) found that students in the UK who enrolled in a content-innovative (extensive use of modeling and technology) first-year college mathematics course were more likely to retain their STEM intentions compared to students enrolled in a traditional course.

In this study we wondered if being engaged was due to students being in different classes or, instead, experiencing the same classes differently. To understand the profiles of the four types of students involved in this study we first explored a number of variables related to student demographics and preparation. 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. 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.

6.2 Discussion

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 in 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 he 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 other students how to solve specific problems, the student may not perceive the instructor as doing so for them personally. 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 connect what the instructor is doing in class to what they are being asked to do on homework or exams less often, 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 one's instructor has prepared extra materials to increase understanding is a component of persistence in calculus among STEM intending students. Reporting this activity 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 rather than 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 of whole-class discussion. Instead, Persisters experience high levels of whole-class discussion and Switchers experience low levels of discussion, even within the same class.

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 the students that are not explicitly included in the discussion may not perceive this as a *whole-class* discussion. In classes with more than ten students it is difficult to engage all students in a discussion. Instructors are likely to engage the students that are easiest to engage: who clearly articulate their thinking and whose thinking will help further the instructor's learning goals. Wagner, Speer, and Rossa (2007) provide an account of one instructor's 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 the instructor had during this process, including how to productively draw on students' incorrect ideas and how to "cover" all of the material in the course. One way to solve these problems is to engage the students who will answer correctly and quickly. Our analyses suggest that this solution may be detrimental to 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 these, 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 students being required to explain their thinking on exams. Thus, the perception that an instructor infrequently requires their students to explain their thinking on exams is predictive of students switching their 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 exam. Instead, there is a relationship between the perception that an instructor requires his or her students to explain their thinking exams and the intention 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 frequency of lecture, *and* where they do not perceive whole-class discussions, being shown how to solve problems, and being given extra material for difficult topics. One common difficulty when implementing student-centered pedagogy is navigating the continuum between pure discovery and pure telling (Rasmussen and Marrongelle 2006). A class which students perceive as having low levels of lecture and low levels of support (in the form of materials, direction, and class discussion) is potentially indicative of a poorly implemented pure discovery environment. The result that more Switchers reported this type of environment than Persisters provides evidence that instructors implementing student-centered instruction need to be attentive towards supporting their students' learning through appropriate instructional approaches.

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 into 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.

6.3 Limitations and implications

There are several limitations to this study. First, analyses are based on self-reporting and are therefore subject to the potential biases and deficiencies characteristic of all self-report survey methodology. These results would be strengthened by additional research that triangulates self-report data with other sources such as classroom observation. Second, our findings indicate statistically significant *associations* between calculus persistence and perceived pedagogy, but do not untangle the potentially intricate relations of *causality* among these variables. Additional longitudinal and/or qualitative research designs would provide greater insight into potential causal dependencies between STEM persistence and classroom experience.

Nevertheless, taken together, these results have significant implications for the classroom environment. First, for initially STEM intending students, who make up the majority of first year mathematics courses in the US and elsewhere, a classroom that deviates from tradition may present a violation of student expectations about mathematics instruction in ways that ultimately bear on their persistence in STEM. Further research is needed to explore how experiences in non-lecture style mathematics classrooms are influencing decisions of STEM intending students to pursue more non-compulsory mathematics, such as calculus. Moreover, when more innovative pedagogical activities, such as whole-class discussion, are implemented, student persistence in calculus depends on their *equitable* implementation.

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