Course Repetition in College-level Mathematics Courses among Community College Transfer Students*

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Mathematics literacy is essential for many tasks in daily life and work. There is an expectation that all college students will develop mathematical reasoning during their college education. At the same time, math coursework serves as a hurdle to earning a credential for many students, potentially limiting students' ability to continue their participation in higher education, particularly for those who enter college underprepared for college-level math courses and instead must initially enroll in developmental education (dev-ed) (e.g., Bailey, Jeong, & Cho, 2010). Among community college students who hope to transfer to a baccalaureate-granting institution, taking the "right" math course that aligns with their intended program of study is vital to help them make progress toward their degree and avoid inefficient course-taking patterns. In this study, I will describe math course-taking patterns among students who transferred from community colleges to public universities in Texas and examine the relationship between course redundancy (hereafter *repetition*) and college outcomes (cumulative grade point average (GPA), bachelor's degree attainment within six-years, time to a bachelor's degree and accumulated excess credits).

Although U.S. higher education institutions traditionally required all students to take college algebra to acquire necessary foundational skills, recent reform efforts such as the Dana Center Mathematics Pathways and Carnegie Math Pathways encourage students to take an introductory (gateway) college-level mathematics course that fits their needs and majors. While college algebra might still be a required course for STEM majors, non-STEM students might be better served by a math course designed to serve their needs of the studies, such as statistics or quantitative reasoning. More community colleges are making multiple math pathways available to students (Schudde & Meiselman, 2019) and working to create guided pathways toward desired degrees (Jenkins & Pellegrino, 2019). Despite efforts to improve the flexibility of gateway math requirements and to streamline students' pathways toward a bachelor's degree, we have little information about course repetition in mathematics among community college students who transition to bachelor' s-degree-granting institutions.

This study will analyze how course repetition patterns among community college transfer students in Texas predict student college outcomes (cumulative GPA, bachelor's degree attainment, time to degree, and excess credits). Using data from the Texas Educational Research Center, I leverage longitudinal statewide administrative records for the 2011-2012 and 2012-2013 community college entrants who transferred to a university within six years of college entry and track students' academic progress over six years.

Why Mathematics Course-taking and Repetition Matter for Student Success

Although many student academic decisions can influence a student’s overall success in higher education, a wealth of research has suggested that mathematics course taking predicts whether a student successfully persists at their institution and graduates with their degree (Adelman, 2005; Bahr et al., 2017; Calcagno et al., 2007). A handful of studies focus on course-taking patterns in a specific sequence at community colleges (e.g., developmental mathematics sequence by Bahr, 2009; college-level mathematics sequence by Bahr et al., 2017; the English as a Second Language (ESL) sequence by Park, 2019). Recent studies examine the course repetition/redundancy at community colleges but focus on math course redundancy between high school and college (Melguizo & Ngo, 2020; Ngo & Velasquez, 2019; Park, Ngo & Melguizo, in press). In this study, I focus on math course redundancy experienced by community college transfer students, describing their course repetition patterns in college-level mathematics sequences across community colleges and public universities.

In his work on milestones that predict transfer and associate degree attainment among community college students, Adelman (2005) found credits accrued in college-level mathematics during the first year were positive predictors. Additional college-level math credits earned throughout college were associated with an increase in the likelihood of earning a bachelor's degree (Adelman, 2005). Similarly, Calcagno, Crosta, Bailey, and Jenkins (2007) analyzed the transcript data of a cohort of first-time community college students in Florida. Applying event history modeling, they examined the probability of earning a community college credential in any given term for students who had previously enrolled in a remedial math course. Among dev-ed math students, those who took and passed the first college-level math course were much more likely to graduate in any given semester. Research also suggests the timing of completing college-level math has important implications for student progress, particularly in certain programs of study (Calcagno et al., 2007; Zhang, 2019). For example, Zhang (2019) found that transfer students who took at least a college-level mathematics course in their first semester at a four-year institution were more likely to earn a STEM bachelor's degree than a non-STEM bachelor's degree.

Beyond examinations of transcripts, recent studies have explored redundancy, also known as misalignment, between high school and college mathematics courses at community colleges (Melguizo & Ngo, 2020; Ngo, 2020; Ngo & Velasquez, 2019; Park, Ngo, & Melguizo, in press). Even though high school graduates show college-ready in mathematics using different standards such as high school GPA, high school mathematics courses, and standardized math test scores, they may still require taking remedial mathematics courses (Melguizo & Ngo, 2020).

Community college students cannot escape "math traps", "when students never go beyond their highest level of math in high school". (Ngo & Velasquez, 2019, p. 9). Therefore, students are placed in mathematic classes that they took the same or lower-level courses at high school (Ngo & Velasquez, 2019). The math misalignment might lead to a decrease in pursuing STEM pathways among STEM-aspiring students (Park, Ngo & Melguizo, in press). Misalignment and course redundancy vary by student socio-economic backgrounds, gender and race (Ngo, 2020; Ngo & Velasquez, 2019).

A handful of studies focus on course-taking patterns in a specific sequence at community colleges (e.g., developmental mathematics sequence by Bahr, 2009; college-level mathematics sequence by Bahr et al., 2017; the English as a Second Language (ESL) sequence by Park, 2019). Bahr (2008) illustrated that most students placed in remedial math course sequence never reach the college-level math courses, instead repeating their developmental math courses. Being stuck in a developmental sequence has important repercussions—students must complete at least one college-level math course (if not more) to satisfy degree requirements. In high return majors, the math sequence may include several courses. For example, the majority of STEM majors require students to take at least Calculus-I. Students would need to finish (or enter with) coursework in that sequence—such as college algebra, trigonometry, pre-calculus, calculus (Bahr et al., 2017). Bahr et al. (2017) used transcript data to investigate community college students' progress through college-level mathematics sequences. However, those studies did not focus on transfer students' course-taking patterns over community college and university. Also, those studies did not examine the redundancy or repetition of mathematics courses at community colleges.

In this study, I examine course repetition of community college transfer students' pathways through mathematics sequences in Texas. Leveraging the common course numbering system in Texas, I track student course-taking patterns across community colleges and universities. First, I capture what percentage of students repeat the same or lower level college-level mathematics courses, among those who already successfully earned credit from courses in that sequence. Second, I discuss where (what sectors) students repeat those math courses. To further understand within-sector repetition (at either community colleges or universities), I also explore whether repetition occurred across multiple institutions or within the same institution. Third, I compare student college outcomes (cumulative GPA, bachelor's degree attainment, time to degree, and excess credits) by math repetition patterns (ever-course repeaters versus never-course repeaters). The study's findings provide an empirical foundation for policy and practice to advance our understanding of course redundancy in mathematics sequences across sectors and offers insights about the implications of math course repetition for student outcomes.

Types of Course Repetition

In this paper, I describe two types of course repetition: 1) *horizontal repetition*: taking additional course(s) at the introductory (gateway) college-level (though in a different math sequence) as a required course already taken; 2) *vertical repetition*: taking one or more additional college-level courses at the same or a lower level than a course previously earned in a specific sequence. Both types of course repetition can lead students to accrue additional, potentially extraneous, credits.

Figure 1: Horizontal and Vertical Course Repetitions in Mathematics

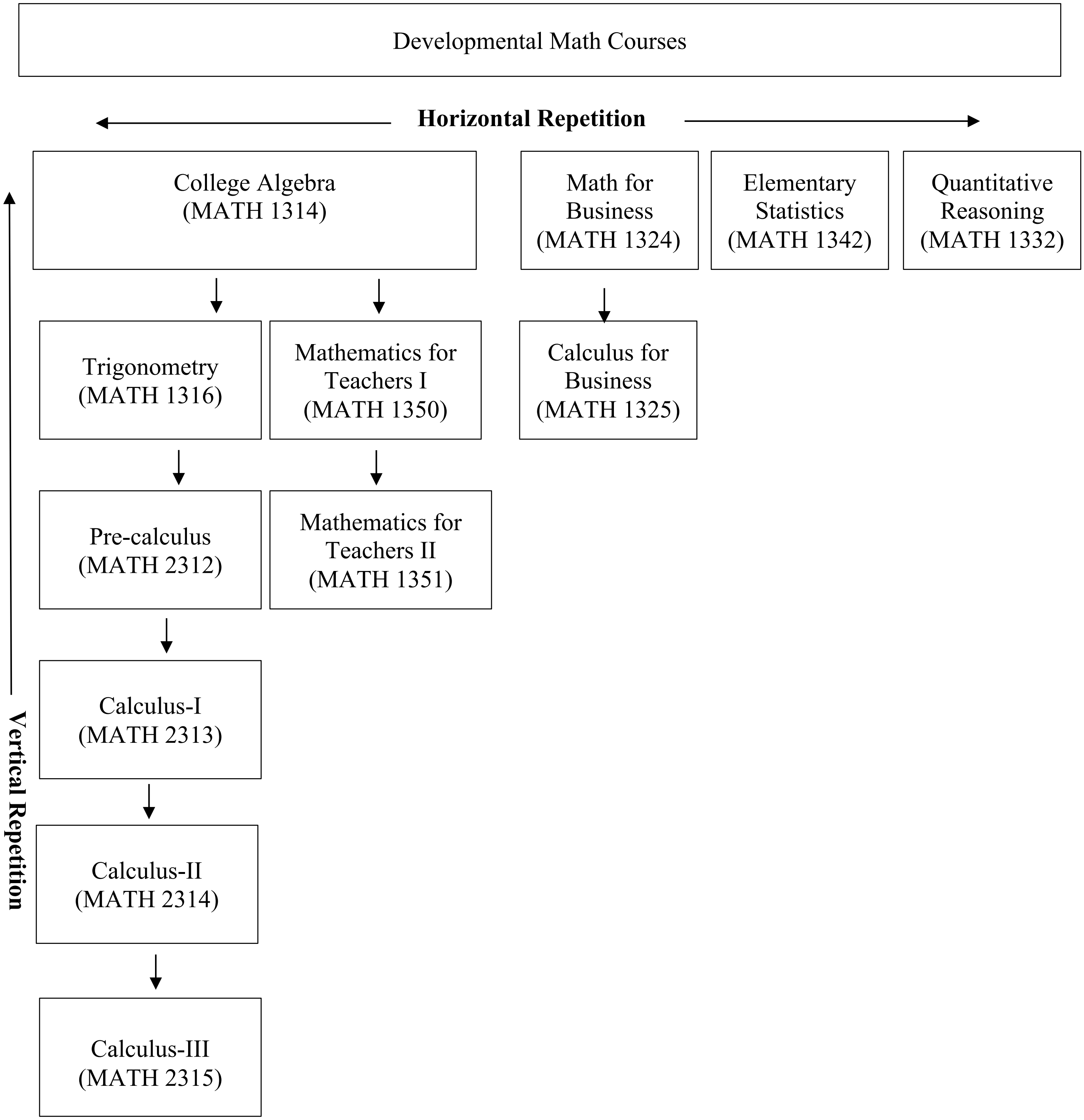

Figure 1 illustrates the two types of math course repetition, where students repeat math courses either by taking an additional course at the same level from a different sequence (horizontal repetition) or repeating courses in the same sequence (vertical repetition, which can include starting earlier in a given sequence). I capture horizontal repetition primarily as patterns where students complete an introductory college-level math course (e.g., college algebra, math for business, quantitative reasoning, or elementary statistics) with a passing grade and subsequently take a different introductory college-level math course. For instance, horizontal repetition occurs when a community college student takes college algebra in the first semester and quantitative reasoning in the second semester. Vertical repetition—retaking the same or a lower college-level math course within a prescribed sequence—occurs when a student retakes college algebra or trigonometry after passing trigonometry.

Due to my interest in community college transfer students and the potential for course redundancy when moving between institutions, I examine where course redundancy occurs. Course repetitions can occur during students' enrollment at a community college and/or after they transfer to a university. For example, if a student passed both Math for Business (MATH 1324) and college algebra (MATH 1314) at a community college before transferring to a four-year institution, that student experienced horizontal repetition at the community college. However, if the student instead took college algebra (MATH 1314) after transferring to a four-year institution, the horizontal repetition would have occurred at the university. Knowing where the bulk of course repetitions occur can inform policy and practice. For that reason, I delineate between four different course repetition patterns based on the type of math course repetition (horizontal vs vertical) and the sector in which coursework is repeated (community college vs. university). Table 1 shows the definition of each pattern of course repetitions: vertical repetition at the community-college level (*Pattern 1*), vertical repetition at the university level (*Pattern 2*), horizontal repetition at the community-college level (*Pattern 3*), and horizontal repetition at the university level (*Pattern 4*).

Table 1.
Four patterns of course repetitions

		Community College	University
Vertical Repetition	Pattern 1	Passed college algebra and retook college algebra	-
	Pattern 2	Passed college algebra	Retook college algebra
Horizontal Repetition	Pattern 3	Passed college algebra and then took quantitative reasoning	-
	Pattern 4	Passed college algebra	Took quantitative reasoning

I also capture a combined definition of the four patterns of repetition to assess whether students *ever-repeated* (refers to students who repeated a math course, either horizontally or vertically, at least once) or *never-repeated* (refers to students who never repeated a math course). Ever-vertical repeaters refer to the students who vertically repeat at least one course at the community college level *(Pattern 1)* or the university level *(Pattern 2).* On the other hand, never-vertical repeaters refer to students who never vertically repeat a math course at neither a community nor a university. The same logic can be applied to ever- and never-horizontal repeaters.

Research Questions

In this study, I am guided by the following research questions:

1. To what extent do community college transfer students experience horizontal and vertical math course repetition?
    a. To what extent do horizontal and vertical course repetitions occur at a community college (before transferring) and a university (after transferring)?

b. For course repetitions prior to transfer, to what extent do horizontal and vertical course repetitions occur within a single institution or across multiple institutions?

2. Do horizontal and vertical course repetitions vary by students' characteristics (race, age, and gender)?
3. Do horizontal and vertical course repetitions vary by students' college experiences (e.g., financial aid exposure: FAFSA filers status, Pell-grant recipients' status; enrollment status; credit accrual: developmental, core, and field of study credits)?
4. Do vertical and horizontal course repetitions predict transfer students’ college outcomes, including earning a bachelor's degree, time to a bachelor's degree, excess credits, and cumulative GPA?

Data and Sample

I used data from the Texas Higher Education Coordinating Board obtained from the Texas Education Research Center's (ERC). The sample for this study included first-time community college starters in 2011-2012 and 2012-2013 academic years in Texas who transferred to a four-year institution within six years of their community college enrollment. Analytical samples differ for vertical and horizontal repetition analyses. The analytical sample for horizontal repetition analysis includes students who took and passed at least one of the four introductory college-level courses (college algebra, elementary statistics, quantitative reasoning, and business for math) at a community college. However, the vertical repetition sample analysis includes all students who took and passed any college-level course at a community college. In other words, those analytical samples indicate total students eligible for each type of math course repetition. The final analytic sample for vertical repetition captured 36,079 community college entrants who passed at least one college-level mathematics course at a community college. In contrast, the analytical sample for horizontal repetition captured 33,205 transfer students who passed at least an introductory math course at a community college.

Identifying First College-level Math Courses and Creating Repetition Measures

To examine college-level mathematics course repetitions among community college transfer students, I focused on identifying and matching math courses across public community colleges and four-year universities in Texas. The Texas Common Course Numbering System (TCCNS) provides the lists of college-level mathematics courses with their prefixes and numbers for both public two-year and four-year colleges (e.g., MATH 1314 for college algebra). As TCCNS lists do not include all university math courses, I used the Texas Transfer Inventory Guide obtained from the Dana Center, which shows math courses aligned across all two-year and four-year public institutions in Texas (Dana Center, 2019). I added the Dana Center's transfer inventory list to the list of college-level math courses I obtained from TCCNS and matched those math courses' prefixes and numbers across institutions.

I merged the resulting list of math courses available at Texas community colleges and universities with the student-level transcript data from the ERC. I created a flag for each student's math courses grouped into 12 types of college-level math categories (please refer back to Figure 1). For each semester in which the student was enrolled, I identified the community college transfer student's math courses at both community colleges and universities. I flagged the semesters of college-level mathematics courses that students took and passed (D or above) for the first time at a community college.

If students attempted the same or a lower level course (whether at a community college or university) after receiving a passing grade, I marked those courses as course repetition. For example, a community college transfer student took and passed Math for Teachers-I (MATH 1350) in the first semester at a community college and then attempted the prerequisite course college algebra (MATH 1314) in the second semester at a community college. This course-taking pattern was coded as a vertical repetition at a community college. For the purposes of addressing research question 4, I also created a dichotomous measure of ever vs. never-repeating a math course; for that measure, this student would be categorized as an ever-vertical repeater.

Analytical Strategy

To address the final research question, I fitted a series of stepwise OLS (ordinary least square) regression models[1], entering groups of variables sequentially into the models, to examine the relationship between math course repetition (captured separately as ever-vertical and ever-horizontal repeating) and college outcomes (cumulative GPA, bachelor's degree attainment within six-years, time to bachelor's degree completion and accumulated excess credits) as control measures were added to the model. I ran separate regressions for two different independent variables of interest—ever-horizontal repetition and ever-vertical repetition—and on each outcome (i.e., I ran the full regression model separately for the four outcomes using the ever-horizontal repetition measure as the independent variable of interest and repeated the same process for the ever-vertical repetition measure). The regressions for cumulative GPA and bachelor's degree attainment models included all community college transfer students, whereas the analytic sample for time to bachelor's degree and excess credits included only students who earned a bachelor's degree and accumulated at least 80[2] college-level semester hour credits.

[1] I also ran logistic regression for bachelor’s degree attainment (as is sometimes preferred for binary outcomes), but found similar results. Because OLS models are easier to interpret (where each additional unit in the coefficient represents a one-point change in the predicted probability of the outcome), I report OLS results.

[2] I excluded students who were fewer than 80 credits from this study because student might have earned out of state credits that were not captured in ERC (Fink et al., 2018).

The models included several variables I expected to influence student outcomes, including demographic characteristics, enrollment patterns, and achievement measures. I added various demographic criteria, such as race, gender, age, and financial aid receipt, associated with community college persistence and transfer (Bailey, Jenkins, & Leinbach, 2005; Schudde, 2019). I could not control for family income because doing so would have drastically reduced the final analytic sample (the measure is only available for FAFSA filers). Instead, I included a measure of ever having received the Pell Grant and an indicator for whether students applied for financial aid. Enrollment patterns, such as stopping out (breaks in college followed by re-enrollment) or attending part-time, have been linked to persistence and degree attainment (Bailey, Jaggars, & Jenkins, 2015; Fike & Fike, 2008; Park, 2012).

To capture student enrollment patterns, I created measures of enrollment intensity (captured as part-time for students enrolled in less than 12 credits in each term, full-time if enrolled in at least 12 credits in each term, or mixed enrollment) and number of stop-outs (how many times students stopped enrollment and then re-enrolled, other than taking off summer terms). In the final model, I was also able to include other academic measures likely to predict bachelor's degree attainment, such as cumulative GPA across all college credits and whether students earned an associate degree (Belfield, 2013).

Also, I included students' broad major fields at a community college before transferring to a university because student course repetition patterns vary by their pre-transfer majors. Finally, anticipating that students who switched majors after transfer might require additional credits to earn a bachelor's degree (Bailey et al. 2016), I included a dichotomous measure of whether students had a different broad Classification of Instructional Programs (CIP) code (the first two digits) during their semester directly before transfer and during their final semester at the university.

In the first model, I included only the course repetition indicator of interest (either ever-horizontal or ever-vertical repetition). For Model 2, I added background variables: race/ethnicity, gender, international student status, age, and financial aid indicators. In Model 3, I added measures capturing students' enrollment patterns, including enrollment intensity, stop-out counts, associate degree status, whether students switched majors after the transfer, and broad student majors. Finally, Model 4 included additional academic measures, which are developmental math credits earned at a community college and cumulative GPA[3]. In the findings section, I describe results from the final model, which included the course repetition indicator of interest and all control measures. Additional results with the stepwise regression results are available in the Appendix.

Findings

In the following sections, I present the descriptive and inferential findings from analyses. First, I discuss the frequency of mathematics course repetitions among community college transfer students. Second, I describe the ever- and never- horizontal and vertical course repeaters in terms of age, gender, and race/ethnicity. Third, I discuss ever- and never- horizontal and vertical course repeaters by their college experiences, such as enrollment status and financial aid status. Fourth, I discuss the regression results that examine the relationship between course-repetition and college outcomes.

[3] Cumulative GPA was used as a statistical control when predicting bachelor’s degree attainment, time to degree and excess credits.

How typical is math course repetition among community college transfer students? Where does the course repetition occur?

I will discuss both horizontal and vertical course repetition patterns. While horizontal course repetition refers to course repetition occurring among introductory college-level courses (college algebra, math for business, quantitative reasoning, and elementary statistics), vertical repetition patterns refer to course repetitions that occur in a specific sequence.

Table 2.
Horizontal repetition by students' first college-level math course and where they repeated (community college versus university)

	Ever-horizontal Repeaters		Ever-vertical Repeaters	
	N	%	N	%
Ever-Repeaters	13489	40.62	6394	17.22
<u>The institution where repetition occurred</u>				
University	4691	14.13	2760	7.65
Community College	9647	29.05	4050	11.23
Same community college	8421	87.29	3550	87.65
Different community college	1226	12.71	500	12.35
Total Sample (N)	33,205		36,079	

Notes: N (horizontal repetition) captures total students eligible for horizontal repetition (passed an intro math course); N (vertical repetition) captures total students eligible for vertical repetition (ever passed any college-level math). The table presents the number and percentage of eligible students who experienced course repetition overall (first row) and the sector they experienced math course repetition within (university and/or community college—these are not mutually exclusive). For those who experienced math course repetition at a community college, the subsequent rows show whether those course repetitions occurred within the same community college or across different community colleges.

Horizontal Repetition and Vertical Repetition

Table 2 shows the number of and percentage of ever-vertical and ever-horizontal repeaters and where those repetitions occurred. Two-fifths of students (40.6%, n=13,489) took additional introductory college-level math coursework after passing an introductory college-level course (i.e., they took more than one type of gateway math course). As table 2 shows, transfer students are more likely to repeat those courses at a community college (29.1%) compared to at university

(14.1%) (note that some students – about 2.5% – experienced horizontal repetition at both the university and community college level). I further analyzed the patterns of course repetition before transfer as to whether the repetitions occurred within the same community college or a different community college.

Findings revealed that 87% of the horizontal course repetitions before the transfer occurred within a single institution. Table 2 also shows that 17.2% of transfer students retook the same level or a lower-level course within a specific sequence. While the vertical repetition rate was 11.2% at the community college level, the same percentage was 7.7% at the university level (about 1.7% of students experienced vertical repetition within both sectors). Similar to horizontal repetition, vertical repetition before transfer also occurred more frequently within a single community college (87.6%) than across multiple colleges.

Table 3.

Community College Transfer Students' Background Characteristics and College Experiences by Types of Course Repetition (Vertical and Horizontal Repetition)

	Horizontal Repetition Sample				Vertical Repetition Sample			
	Ever-horizontal repeaters		Never-horizontal repeaters		Ever-vertical repeaters		Never-vertical repeaters	
	(N)	(% or Mean)	(N)	(% or Mean)	(N)	(% or Mean)	(N)	(% or Mean)
Total	13489	40.6%	19,716	59.4%	6,394	17.2%	29,685	82.8%
Race								
White	5,109	40.7%	7,441	59.3%	2,268	16.4%	11,569	83.6%
Black	1,198	42.0%	1,652	58.0%	556	18.3%	2,477	81.7%
Asian	992	53.0%	878	47.0%	466	20.2%	1,841	79.8%
Hispanic	5,459	38.1%	8,872	61.9%	2,791	18.5%	12,338	81.5%
Other	39	39.8%	59	60.2%	19	17.6%	89	82.4%
Two or More	692	45.9%	814	54.1%	294	17.7%	1,371	82.3%
International Student	91	35.8%	163	64.2%	62	19.9%	249	80.1%
Gender								
Female	8,053	42.1%	11,067	57.9%	3,162	15.7%	16,952	84.3%
Male	5,436	38.6%	8,649	61.4%	3,232	20.2%	12,733	79.8%
Age	13,489	19.1	19,716	19.7	6,394	18.7	29,685	19.5
FAFSA Filing Status								
FAFSA Filers	9,977	41.4%	14,148	58.6%	4,839	18.5%	21,267	81.5%
Non-FAFSA Filers	3,512	38.7%	5,568	61.3%	1,555	15.6%	8,418	84.4%
Pell-Grant Recipient Status								
Pell-Grant Recipients	6,799	40.4%	10,046	59.6%	3,291	18.3%	14,671	81.7%
Non-Pell Grant Recipients	6,690	40.9%	9,670	59.1%	3,103	17.1%	15,014	82.9%
Major switcher status								
Major switcher	4,433	44.1%	5,616	55.9%	2,197	20.0%	8,801	80.0%
Non-major switcher	9,056	39.1%	14,100	60.9%	4,197	16.7%	20,884	83.3%
Enrollment Status								
Part-time	402	33.5%	797	66.5%	191	14.4%	1,137	85.6%
Full-time	632	34.7%	1,188	65.3%	268	13.1%	1,774	86.9%

Mixed enrollment	12,455	41.3%	17,731	58.7%	5,935	18.1%	26,774	81.9%
Dual Credit Enrollment								
Dual credit taker	4,181	40.0%	6,266	60.0%	1,960	16.5%	9,908	83.5%
Non-dual credit	9,308	40.9%	13,450	59.1%	4,434	18.3%	19,777	81.7%
Cumulative Dev-ed math credits	13,489	2.07	19,716	2.7	6,394	2.1	29,685	2.3
Cumulative Field of Study credits	13,489	2.92	19,716	2.7	6,394	3.6	29,685	2.9
Cumulative Core curriculum credits	13,489	46.79	19,716	42.8	6,394	48.3	29,685	43.00

Notes. N (horizontal repetition) = 33,205 (this captures total students eligible for horizontal repetition because they passed an intro math course); N (vertical repetition) = 36,079 (this captures total students eligible for vertical repetition because they passed any college-level math). The table shows the characteristics of students who ever experienced (vs. never experienced) horizontal and vertical math course repetition. It presents the number of community college transfer students (N) within different repetition types and the corresponding percentage (%) of students (provided for categorical measures) or means (provided for continuous measures).

Description of Students who Experience Course Repetition

I categorized horizontal and vertical repetition samples into two categories: ever-repeaters and never-repeaters. Table 3 shows student background characteristics and college experiences by the four distinct types (ever-horizontal repeater, never-horizontal repeater, ever-vertical repeater, and never-vertical repeaters). Considering ever- and never-repeaters, I will discuss horizontal and vertical repeaters by student background characteristics (race, gender, international status, and age) in the next paragraph.

The majority (53%) of students who identified as Asian experienced horizontal repetition. The average for White, Black, and Hispanic students was closer to 40%. International students (35.8%) have a lower rate of horizontal repetition than citizens. About 42% of women experienced horizontal math course repetition, whereas about 39% of men did. Male students (20.2%) appear more likely to experience vertical math course repetition rate than female students (15.7%). Never-vertical repeaters (19.5 years-old) are older than ever-vertical repeaters (18.7 years-old).

Table 3 also shows some variation in college experiences across never- and ever-horizontal and vertical repeaters. FAFSA filing status may have a small correlation with experiencing Compared to non-FAFSA filers (38.7% in horizontal repetition and 15.6% in vertical repetition), FAFSA filers (41.4% in horizontal repetition and 18.5% in vertical repetition) have higher rates of both vertical and horizontal repetition in mathematics. While Pell recipients and Non-Pell recipients have similar horizontal repetition rates (respectively, 40.4% versus 40.9%), Pell recipients have higher rates of vertical repetition than non-Pell recipients (18.3% versus 17.1%).

Forty four percent of students who switched majors experienced horizontal course repetition compared with 39% of students who stayed in the same major after transferring to a bachelor's degree granting institution. Similarly, a higher percentage of major switchers experience vertical course repetition compared with non-major switchers. Mixed-enrollment students were more likely than full-time and part-time students to experience both repetition types. While part-time students have a slightly higher rate of horizontal repetition compared to full-time students, the rate of vertical repetition is higher among full-time students than part-time students. Students that had at least one dual credit course have lower rates of both vertical and horizontal repetition than students who did not have any dual credit courses (40.0% versus 40.9% in horizontal, and 16.5% versus 18.3% in vertical).

There were differences in numbers of cumulative developmental math, core, and field of study credits between ever- and never-repeaters in horizontal and vertical repetition. Ever-repeaters in vertical and horizontal categories accumulated more core and field of study credits before transfer than never-repeaters, which is to be expected, since math is a core course and may also be foundational to some fields of study. On average, ever-horizontal repeaters (2.1 dev-ed math credits)—students who took more than one type of introductory college-level math course—accumulated fewer developmental math courses than never-horizontal repeaters (2.7 dev-ed math credits). Similarly, ever-vertical repeaters (2.1 dev-ed math credits), who repeated at least one same or lower-level math course in a specific sequence, on average, accumulated less developmental math courses than never-vertical repeaters (2.3 dev-ed math credits). Compared with never-repeaters in both analytic samples, horizontal and vertical repeaters accrued a somewhat smaller number of dev-ed credits, on average, though the differences were quite small.

Course Repetition and College Outcomes

Table 4 shows the college outcomes (earning a bachelor's degree within six years, semesters enrolled before earning a bachelor's degree, average excess credits, and cumulative GPA) of transfer students by their vertical and horizontal repetition status. On average, the cumulative GPA and rate of bachelor's degree attainment among ever-horizontal repeaters and never-horizontal repeaters look quite similar. Among students who earned a bachelor's degree, ever-horizontal repeaters and never-horizontal repeaters took a similar length of time to finish a bachelor's degree (14.9 semesters versus 14.8 semesters), but the ever-repeaters accumulated about four additional credits compared with their never-horizontal repeater peers.

Vertical repetition patterns are slightly different from horizontal repetition patterns. Although 40% of never-vertical repeaters earned a bachelor's degree within six years, only 30% of ever-vertical repeaters did so. Moreover, never-vertical repeaters had higher GPAs (3.36) than ever-vertical repeaters (2.18 GPA). Among students who earned a bachelor's degree, never-vertical repeaters took slightly less time to complete (15 semesters versus 14.8 semesters). Similar to horizontal repetition, ever-vertical repeaters accumulated more excess credits than their never-vertical peers.

Table 4.
Community College Transfer Students' College Outcomes by Their Course Repetition Categories

	Horizontal Repetition					Vertical Repetition				
	Whole Sample	Ever-vertical repeaters		Never-vertical repeaters		Whole Sample	Ever-vertical repeaters		Never-vertical repeaters	
	(N)	(N)	(Mean)	(N)	(Mean)	(N)	(N)	(Mean)	(N)	(Mean)
GPA	33,205	13,489	3.32	19,716	3.31	36,079	6,394	3.18	29,685	3.36
Bachelor's Attainment	33,205	13,489	0.39	19,716	0.37	36,079	6,394	0.30	29,685	0.40
Time to Degree	12,329	5,191	14.9	7,138	14.8	13,799	1,945	15.0	11,854	14.8
Excess Credits	12,329	5,191	16.46	7,138	12.86	13,799	1,945	19.76	11,854	13.35

Notes: Bachelor's degree attainment refers to the transfer students who earn a bachelor's degree within six years. Among students who earn a bachelor's degree, time to degree was measured by the number of semesters that students attend at both a community college and a four year-institution. Total credits and GPA are measured as cumulative from community college and four-year institutions. Excess credits are the credits attempted by a community college transfer student that exceeded more than the bachelor's degree requirement (120).

Table 5.
OLS Regression Results Examining Relationship Between Horizontal Math Course Repetition and Various Student Outcomes (Cumulative GPA, Bachelor's Degree Attainment within Six-years, Time to Bachelor's Degree (Semesters) and Excess Credits)

Variables	(Model 1) Cumulative GPA	(Model 2) BA Attainment within 6-years	(Model 3) Time to Degree (Semesters)	(Model 4) Excess Credits
Ever-Horizontal Repeater	-0.001	0.005	0.101**	3.593***
	(0.006)	(0.005)	(0.035)	(0.290)
Student Backgrounds	X	X	X	X
College Experiences	X	X	X	X
Cohort Fixed-Effects	X	X	X	X
Observations	29,675	29,675	11,942	11,942
R-squared	0.099	0.150	0.287	0.203

Notes. The table presents coefficients with standard errors in parentheses from ordinary least squares regression models performed on a pooled sample of community college students who entered college in 2011–2012 or 2012–2013, where each column represents a separate regression. Model 1 and Model 2 include students who transferred to a four-year institution. Model 3 and Model 4 include those students who transferred to a four-year institution and earned a bachelor's degree within six years with more than 80 college-level semester credits. All models include cohort fixed effects.
*** p<0.001, ** p<0.01, * p<0.05

Regression Results

To understand whether the relationships between each type of course repetition and college outcomes holds after controlling for student background and college experiences, I ran a series of regressions. Table 5 presents results from regressions estimating the relationship between horizontal math course repetition and student outcomes. After controlling all the background characteristics and college experience indicators, the ever-horizontal repeater status does not predict cumulative GPA and bachelor's degree attainment in model 1 and model 2—illustrating similar findings to the descriptive results. However, model 3 and model 4 results revealed a positive relationship between horizontal repetition status and time to degree and excess credits. After including a full set of statistical controls, the model 3 results indicate that horizontal repetition increases time to a bachelor’s degree by 0.1 semesters. The unadjusted difference in this outcome between the two groups was small, which suggests that differences in the backgrounds and college experiences between horizontal repeaters and non-repeaters contribute to the higher predicted time to degree among horizontal repeaters. Model 4 results suggest that experiencing horizontal course repetition was associated with a 3.6-credit increase in excess credits.

Table 6.
OLS Regression Results Examining Relationship Between Vertical Math Course Repetition and Various Student Outcomes (Cumulative GPA, Bachelor's Degree Attainment within Six-years, Time to Bachelor's Degree (Semesters) and Excess Credits)

Variables	(Model 1) Cumulative GPA	(Model 2)+ BA Attainment within 6-years	(Model 3) Time to Degree (Semesters)	(Model 4) Excess Credits
Ever-vertical Repeaters	-0.161***	-0.065***	0.164***	5.290***
	(0.007)	(0.007)	(0.047)	(0.390)
Student Backgrounds	X	X	X	X
College Experiences	X	X	X	X
Cohort Fixed-Effects	X	X	X	X
Observations	32,334	32,334	13,346	13,346
R-squared	0.111	0.154	0.288	0.215

Notes. The table presents coefficients with standard errors in parentheses from ordinary least squares regression models performed on a pooled sample of community college students who entered college in 2011–2012 or 2012–2013, where each column represents a separate regression. Model 1 and Model 2 include students who transferred to a four-year institution. Model 3 and Model 4 include those students who transferred to a four-year institution and earned a bachelor's degree within six years. All models include cohort fixed effects.
*** p<0.001, ** p<0.01, * p<0.05
+Logistic regression was also performed. The results of the logistic regression were similar to OLS regression. As the interpretation of the OLS regression model is easier, I performed to use the OLS model.

Table 6 presents results from regressions estimating the relationship between vertical math course repetition, and student outcomes (cumulative GPA, bachelor's degree attainment within six-years, time to degree, and excess credits). After including the full set of statistical controls, the results suggest that experiencing vertical course repetition—compared with never experiencing vertical course repetition—was associated with a .16-unit decrease in students' cumulative GPA and a 6.5 percentage decrease in the probability of earning a bachelor's degree within 6 years of initial enrollment at a community college. Among students who earned a bachelor's degree within 6 years, vertical course repetition predicted an increase in time to degree of 0.16 semesters and an increase in excess credits of 5.3 credits.

Discussion and Implications

In this study, I describe the prevalence of math course repetition among community college transfer students in Texas. Descriptive findings illuminate that 40% of students take more than one introductory college-level math course (*horizontal repeaters*), and 17% of students repeat the same or lower math courses in the prescribed sequence (*vertical repeaters*). While it may be the case that some programs require more than one introductory college-level math course, the high rate of horizontal repetition highlights the need for colleges to examine program requirements, advising practices, and transfer processes to reduce unnecessary horizontal duplication. Additionally, the vertical repetition rate suggests that colleges may need to create processes to identify critical courses to provide in-semester supports. Overall, the findings indicate that colleges must examine student course-taking patterns to avoid the accrual of additional credits.

Implementing guided pathways at the state-level could improve students' math course-taking patterns. As community colleges continue to implement guided pathways, they should explicitly develop strategies to avoid course repetition, first focusing on preventing repetition within their institution and then working to prevent it from partner institutions. As recommended in the Texas Pathways strategy, institutions should create clear and coherent program maps that align community college and transfer university programs of study (Flores & Fabianke, 2019; Texas Success Center, 2020). Additionally, colleges can develop meta-majors, which are clusters of programs that lead to similar career goals. By choosing the same appropriate introductory math course for all programs of study in a meta-major, colleges can decrease horizontal repetition for students who enter with at least a broad idea of their area of interest (Texas Success Center, 2019). In line with the implementation of math pathways programs, such as the Dana Center Mathematics Pathways (DCMP), colleges should provide advising in K-12 partner institutions and during college onboarding to give students information about the specific introductory-level mathematics course aligned with their meta-major and career goals. Such planning and advising efforts stand to decrease horizontal course repetition.

One of the challenges that transfer students face is credit loss at a four-year institution (Monaghan & Attewell, 2015). Not all courses are transferable from community colleges or applicable to degree requirements at four-year institutions. As repeating a course is a form of credit loss (those credits now likely count as electives), I initially assumed that math course repetition mostly occurred at the university level (post-transfer). However, findings suggest that the majority of both vertical and horizontal repeats occur at the community college level, contradicting my assumption. Thus, unlike results in the credit loss literature, during the years under study in Texas, the majority of excess credits came from repeated courses within a single community college, suggesting that reforms at the community college level could have the most substantial impact of reducing excess credits due to math repetition in Texas.

To decrease course repetition among students, institutions could develop a couple of different strategies through the implementations of guided pathways. Community colleges could develop data analytics to reduce course repetitions and excess credits. Institutional research (IR) offices at community colleges could use this study's repetition identification strategy and apply it to examine patterns at their institutions. A similar process was outlined in Jenkins and Pellegrino's (2019) case study of San Jacinto College in Texas (presented at the guided pathways kickoff meeting) which highlighted the importance of using data to understand excess credits and demonstrated how the IR office at the college uses students' transcript to identify challenging courses. Similar to the San Jacinto College approach, I recommend that IR offices use data to identify critical courses that their students usually repeat, which will help them target pathways and sequences that could be improved.

Second, as the course repetitions vary by the students' first college-level mathematics course, departments, and advisors can use information gleaned from IR results to enhance their advising practices. For example, half of the calculus for business starters vertically repeated at least one time (either retook calculus for business or math for the business course again). It may be the case that students seeking admission to competitive business programs at a university retake the course to earn a better grade since grade replacement policies at some community colleges allow students to improve their GPAs before transfer. It could also be the case that the material in business calculus was challenging, and students required more support to pass the course. Advisors and business/math department faculty could work together to examine the reasons for this repetition pattern, ensure placement policies correctly identify readiness for calculus, and provide any necessary in-semester support to help students meet their transfer goals during the first attempt at business calculus.

Additionally, IR offices and math departments at community colleges can work together and create an early warning system/flag before students register for a course that appears to be a vertical or horizontal course repetition. Before registration, receiving a warning message about repeating a course paired with information about their program requirements might help students choose more appropriate coursework. Moreover, advisors can also make use of this information and discuss with students the consequences of repeating a course.

When refining programs and policies based on data, institutions should disaggregate by race, gender, and academic preparedness to examine student progress and pinpoint subgroups of students experiencing high rates of course repetition, similar to suggestions in the Texas Success Center's (2019) strategic plan. In the current study, findings from the disaggregated data revealed different results than aggregated data. Examining various rates of course repetition can help colleges determine whether they need to target interventions to best serve their student populations. These results suggest that necessary changes to college practices may vary when taking into account the racial/ethnic makeup of repeaters.

The course repetition framework can be used to analyze course repetition patterns in community colleges and future research studies. Although I used data from cohorts that entered college prior to the implementation of guided pathways in Texas, the framework can guide institutional teams implementing reforms to "optimize the applicability of community college credits" in the transfer process (Texas Success Center, 2019, p. 4) and provide an additional measure of institutional improvement during guided pathways reform efforts (i.e., if rates of horizontal course repetition at a community college decrease, that would offer some evidence that Guided Pathways may serve to help students avoid repeating equivalent math courses from different sequences). Moreover, researchers can use the framework to apply the types of course repetitions to other contexts and student populations, as well as to analyze how the course repetition patterns changed over time (from one cohort to another cohort).

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Table 5.

OLS Regression Results Examining Relationship Between Horizontal Math Course Repetition and Various Student Outcomes (Cumulative GPA, Bachelor's Degree Attainment within Six-years, Time to Bachelor's Degree (Semesters) and Excess Credits)

Variables	(Model 1) Cumulative GPA	(Model 2)+ BA Attainment within 6-years	(Model 3) Time to Degree (Semesters)	(Model 4) Excess Credits
Ever-Horizontal Repeater	-0.001	0.005	0.101**	3.593***
	(0.006)	(0.005)	(0.035)	(0.290)
Race (Reference = White)				
Asian	0.051***	-0.060***	0.025	3.407***
	(0.013)	(0.012)	(0.078)	(0.640)
Black	-0.197***	-0.033**	-0.254***	4.520***
	(0.011)	(0.010)	(0.071)	(0.575)
Hispanic	-0.106***	-0.048***	0.063	0.645*
	(0.007)	(0.006)	(0.040)	(0.323)
Two or More Race	-0.041**	-0.064***	-0.281**	0.607
	(0.014)	(0.013)	(0.086)	(0.705)
Other	-0.045	0.041	-0.202	0.690
	(0.052)	(0.048)	(0.290)	(2.367)
Female (Reference = Male)	0.117***	0.056***	-0.215***	-1.815***
	(0.006)	(0.006)	(0.036)	(0.297)
International Student	0.079*	-0.027	-0.509*	-2.011
	(0.032)	(0.030)	(0.199)	(1.623)
Age	0.021***	-0.001	-0.035***	-0.422***
	(0.001)	(0.001)	(0.004)	(0.031)
Pell-grant Recipients	-0.015*	-0.074***	0.249***	1.908***
	(0.008)	(0.007)	(0.046)	(0.375)
FADS status	0.028***	-0.041***	2.091***	6.707***
	(0.008)	(0.008)	(0.048)	(0.392)
Enrollment Pattern (Reference = Part-time)				
Full-time	0.047*	0.273***	-0.443***	5.310***
	(0.019)	(0.018)	(0.123)	(1.008)
Part-time	-0.018	0.146***	-0.354**	6.544***
	(0.015)	(0.014)	(0.111)	(0.905)
The number of Stop-out	-0.108***	-0.161***	0.116*	-5.425***
	(0.005)	(0.005)	(0.046)	(0.377)
Earn Associate Degree	0.094***	-0.050***	0.180***	3.033***
	(0.006)	(0.006)	(0.036)	(0.290)
Major Switchers	-0.032***	-0.002	-0.236***	3.851***
	(0.006)	(0.006)	(0.038)	(0.308)

Broad Major Category at com. college (Reference = Indust., Manufac., and constr.)				
Natural Sciences	0.115***	-0.127***	0.353*	5.085***
	(0.027)	(0.025)	(0.145)	(1.184)
Business	0.068**	-0.015	0.294*	-1.995
	(0.025)	(0.023)	(0.127)	(1.041)
Social and Behavioral sciences	0.047	-0.000	0.087	-4.138***
	(0.027)	(0.025)	(0.140)	(1.141)
Communication Sciences	0.078*	-0.031	0.337	-3.387*
	(0.033)	(0.031)	(0.179)	(1.460)
Literature, Linguistic and Fine Arts	0.095***	-0.147***	0.693***	2.129
	(0.029)	(0.027)	(0.158)	(1.287)
Math and Computer Sciences	0.134***	-0.160***	0.876***	4.138**
	(0.029)	(0.027)	(0.167)	(1.366)
Education, Social Services and Policy	0.019	-0.058*	0.271*	-2.855**
	(0.025)	(0.023)	(0.132)	(1.077)
Engineering and Related Fields	0.134***	-0.198***	1.041***	10.572***
	(0.028)	(0.026)	(0.164)	(1.342)
Humanities and Liberal Arts	0.065**	-0.105***	0.450***	-1.686
	(0.024)	(0.022)	(0.123)	(1.008)
Service Oriented	0.063*	-0.036	0.200	2.210
	(0.030)	(0.028)	(0.159)	(1.300)
Health	0.110***	-0.150***	0.503***	0.473
	(0.026)	(0.024)	(0.141)	(1.148)
Cum. Dev-ed Math Credits	0.014***	0.197***	-0.747***	1.324***
	(0.001)	(0.005)	(0.041)	(0.053)
Cumulative GPA		-0.017***	0.082***	
		(0.001)	(0.006)	
Cohort-2013	0.001	0.008	-0.926***	-4.470***
(Reference = 2012)	(0.006)	(0.005)	(0.037)	(0.300)
Constant	2.867***	-0.122***	17.028***	129.223***
	(0.031)	(0.033)	(0.220)	(1.482)
Observations	29,675	29,675	11,942	11,942
R-squared	0.099	0.150	0.287	0.203

Notes. The table presents coefficients with standard errors in parentheses from ordinary least squares regression models performed on a pooled sample of community college students who entered college in 2011–2012 or 2012–2013. Model 1 and Model 2 include students who transferred to a four-year institution. Model 3 and Model 4 include those students who transferred to a four-year institution and earned a bachelor's degree within six years. All models include cohort fixed effects.

*** p<0.001, ** p<0.01, * p<0.05

+Logistic regression was also performed. The results of the logistic regression were similar to OLS regression. As the interpretation of the OLS regression model is easier, I performed to use the OLS model.

Table 6.
OLS Regression Results Examining Relationship Between Vertical Math Course Repetition and Various Student Outcomes (Cumulative GPA, Bachelor's Degree Attainment within Six-years, Time to Bachelor's Degree (Semesters) and Excess Credits)

Variables	(Model 1) Cumulative GPA	(Model 2)+ Bachelor's Degree Attainment	(Model 3) Time to Degree by Semesters	(Model 4) Excess Credits
Ever-vertical Repeaters	-0.161***	-0.065***	0.164***	5.290***
	(0.007)	(0.007)	(0.047)	(0.390)
Race (Reference = White)				
Asian	0.070***	-0.046***	-0.045	3.678***
	(0.012)	(0.011)	(0.069)	(0.563)
Black	-0.190***	-0.038***	-0.242***	3.801***
	(0.010)	(0.010)	(0.068)	(0.559)
Hispanic	-0.105***	-0.053***	0.071	0.322
	(0.006)	(0.006)	(0.038)	(0.310)
Two or More Race	-0.035**	-0.059***	-0.238**	1.195
	(0.013)	(0.012)	(0.081)	(0.662)
Other	-0.013	0.025	-0.091	1.565
	(0.049)	(0.046)	(0.277)	(2.278)
Female (Reference = Male)	0.108***	0.057***	-0.236***	-1.635***
	(0.006)	(0.005)	(0.034)	(0.283)
International Student	0.098***	-0.018	-0.511**	-2.445
	(0.029)	(0.027)	(0.176)	(1.442)
Age	0.020***	-0.001*	-0.035***	-0.318***
	(0.001)	(0.001)	(0.004)	(0.030)
Pell-grant Recipients	-0.016*	-0.073***	0.271***	2.050***
	(0.007)	(0.007)	(0.043)	(0.356)
FADS status	0.035***	-0.038***	2.091***	6.839***
	(0.008)	(0.007)	(0.045)	(0.370)
Enrollment Pattern (Reference = Part-time)				
Full-time	0.055**	0.263***	-0.363**	5.765***
	(0.018)	(0.017)	(0.114)	(0.939)
Mixed enrollment	-0.008	0.142***	-0.267**	6.920***
	(0.015)	(0.014)	(0.102)	(0.840)
The number of Stop-out	-0.107***	-0.166***	0.095*	-5.561***
	(0.005)	(0.005)	(0.044)	(0.362)
Earn Associate Degree	0.085***	-0.055***	0.217***	3.356***
	(0.006)	(0.005)	(0.034)	(0.279)
Major Switchers	-0.027***	-0.002	-0.211***	3.851***
	(0.006)	(0.005)	(0.036)	(0.293)

Broad Major Category at CC (Reference = Industrial, Manufacturing, and construction)				
Natural Sciences	0.138***	-0.099***	0.290*	4.571***
	(0.026)	(0.024)	(0.138)	(1.133)
Business	0.069**	-0.010	0.263*	-1.765
	(0.024)	(0.023)	(0.125)	(1.028)
Social and Behavioral sciences	0.042	-0.002	0.052	-3.879***
	(0.026)	(0.025)	(0.137)	(1.127)
Communication Sciences	0.068*	-0.028	0.287	-2.972*
	(0.033)	(0.031)	(0.175)	(1.435)
Literature, Linguistic and Fine Arts	0.084**	-0.145***	0.648***	2.647*
	(0.028)	(0.026)	(0.154)	(1.266)
Math and Computer Sciences	0.162***	-0.101***	0.604***	3.555**
	(0.027)	(0.026)	(0.147)	(1.210)
Education, Social Services and Policy	0.014	-0.058*	0.225	-3.168**
	(0.025)	(0.023)	(0.129)	(1.062)
Engineering and Related Fields	0.173***	-0.169***	0.746***	8.478***
	(0.026)	(0.025)	(0.147)	(1.207)
Humanities and Liberal Arts	0.071**	-0.103***	0.440***	-0.694
	(0.023)	(0.022)	(0.121)	(0.995)
Service Oriented	0.052	-0.030	0.191	2.331
	(0.029)	(0.028)	(0.156)	(1.283)
Health	0.105***	-0.152***	0.525***	1.991
	(0.025)	(0.024)	(0.138)	(1.136)
Cum. Dev-ed Math Credits	-0.015***	-0.018***	-0.747***	1.234***
	(0.001)	(0.001)	(0.039)	(0.052)
Cumulative GPA		0.193***	-0.954***	-5.233***
		(0.005)	(0.035)	(0.319)
Cohort-2013	-0.001	0.007	0.084***	-4.802***
(Reference = 2012)	(0.005)	(0.005)	(0.006)	(0.285)
Constant	2.917***	-0.081*	16.971***	145.308***
	(0.030)	(0.032)	(0.211)	(1.732)
Observations	32,334	32,334	13,346	13,346
R-squared	0.111	0.154	0.288	0.215

Notes. The table presents coefficients with standard errors in parentheses from ordinary least squares regression models performed on a pooled sample of community college students who entered college in 2011–2012 or 2012–2013. Model 1 and Model 2 include then students who transferred to a four-year institution. Model 3 and Model 4 include those students who transferred to a four-year institution and earned a bachelor's degree within six years of enrollment. All models include cohort fixed effects.
*** p<0.001, ** p<0.01, * p<0.05
+Logistic regression was also performed. The results of the logistic regression were similar to OLS regression. As the interpretation of OLS regression.