CCRC COMMUNITY COLLEGE RESEARCH CENTER

TEACHERS COLLEGE, COLUMBIA UNIVERSITY

Toward a Practical Set of STEM Transfer Program Momentum Metrics

John Fink
Taylor Myers
Daniel Sparks
Shanna Smith Jaggars

October 2021

CCRC Working Paper No. 127

Address correspondence to:

John Fink
Senior Research Associate, Community College Research Center
Teachers College, Columbia University
525 W. 120th St., Box 174
New York, NY 10027
212.678.3091
Email: john.fink@tc.columbia.edu

This material is based upon work supported by the National Science Foundation under Grant No. 1915191. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Abstract

Nearly two decades into the "completion agenda" in higher education, many community colleges have adopted collegewide reforms designed to improve stubbornly flat rates of student success and address persistent equity gaps. The longer-term effects of such collegewide reforms may take years to observe. In the meantime, college leaders need to know whether changes they make in the short run are associated with longer-term student success. Measuring the progress and effects of institutional reform is particularly vital in economically important STEM fields. Drawing on administrative records from transfer-intending community college starters across three states, this study develops and explores potential indicators of early STEM program momentum. We find that a relatively simple set of STEM momentum metrics—notably early completion of calculus or non-math STE coursework specified in statewide STEM transfer pathways and, to a lesser degree, the prerequisites to such courses—are reliable indicators of subsequent STEM transfer and bachelor's degree attainment. Our findings provide support for the use of the STEM momentum metrics to formatively evaluate reforms aimed at strengthening STEM transfer outcomes and closing equity gaps in STEM bachelor's degree attainment.

Table of Contents

1. Introduction

Nearly two decades into the “completion agenda” in higher education, many community colleges have adopted collegewide reforms designed to improve stubbornly flat rates of student success and address persistent equity gaps (Bailey et al., 2015; Jenkins et al., 2020). The longer-term effects of such collegewide reforms may take years to observe. In the meantime, college leaders need to know whether changes they make in the short run are associated with longer-term student success. Accordingly, college leaders have turned to “leading indicators” or “early momentum” measures, which are meant to provide timely, formative feedback to support continuous improvement as collegewide reforms are implemented and scaled up (Jenkins & Bailey, 2017).

At the institutional level, metrics of early momentum are program-agnostic. For example, the widely used metric of first-year credit accumulation carries an intuitive and consistent meaning, regardless of whether students are aiming for a degree in business, engineering, education, or a variety of other fields. Yet on the level of an individual student, program-specific coursetaking may be the strongest indicator of eventual transfer or graduation (Denley, 2016; Jenkins & Cho, 2012, 2014). Moreover, institutional improvement aimed at greater student success requires the involvement of faculty and administrators within specific academic programs, who may be better equipped to engage in reform efforts if metrics are contextualized to their own programs (Bailey et al., 2015). While Wang (2017) has articulated its theoretical importance, thus far the field lacks a framework for developing and deploying reliably predictive and practical program-specific momentum metrics.

Measuring the progress and effects of institutional reform is particularly vital in the economically important fields of Science, Technology, Engineering, and Math (STEM). Community colleges represent an important potential pipeline for diverse talent into STEM fields, which have struggled even more than other fields to increase representation of Black and Hispanic workers, women, and individuals from other minoritized groups (Riegle-Crumb et al., 2019). More than a million students enter higher education through community colleges each year, including large proportions of Black, Hispanic, low-income, and first-generation students (American Association of Community Colleges, 2021). Yet few community college students progress to advanced

STEM coursework and transfer into a STEM bachelor's program. For example, of 1.7 million students nationwide who started higher education at a community college in the 2007–08 academic year, only about 3% ever transferred and completed a STEM bachelor's degree (Jaggars et al., 2016). Underlying these low completion rates are challenges resulting from ineffective institutional practices and misaligned transfer systems, which have disproportionately impacted STEM-aspiring women, students of color, and other marginalized groups (Wang, 2020). Despite its potential for broadening access to STEM bachelor's degrees, the STEM transfer pathway is underperforming and inequitable.

This study develops and explores potential indicators of early program momentum, with a focus on transfer pathways to baccalaureate degrees in STEM. We draw on administrative records from nearly 270,000 transfer-intending students who began at 70 community colleges across three state systems and, as a basis for comparison, nearly 57,000 students who began at 26 broad-access, regional four-year campuses in the same states. We leverage these data to address the following research questions:

1. Can a simple set of STEM momentum metrics predict students' long-term transfer outcomes at a similar or superior level as widely used general early momentum metrics?
2. Are these STEM momentum metrics reliable across a wide variety of institutional contexts and student groups, particularly those students who are historically underrepresented in STEM?
3. To what extent do these metrics reflect students' intent to study STEM, students' success within STEM, and institution-specific efforts to support STEM pathways?

Our findings suggest that STEM-specific coursetaking measures are just as or more predictive of subsequent STEM transfer outcomes than general early momentum measures and that the most consistently useful indicator is first-year completion of STEM courses specified on statewide STEM transfer pathways. However, relatively few community college students complete this type of STEM coursework in their first year; students are instead more likely to concentrate on completing prerequisite "foundational"

STEM courses or other STEM courses that may transfer to a four-year college without fulfilling STEM bachelor's degree requirements. Despite the potential of community college STEM transfer pathways to broaden access to STEM careers for underrepresented groups such as Black and Hispanic students and women, we find low and inequitable rates of early STEM transfer momentum. Encouragingly, however, we find that early completion of key STEM transfer courses is a reliable predictor of subsequent STEM transfer success across student demographic subgroups and institutional contexts. Taken together, our findings suggest that a promising approach toward increasing STEM bachelor's attainment and closing equity gaps in STEM fields is to focus on helping first-year students complete specific courses designated on their state's STEM transfer pathways.

In the remainder of this introduction, we first situate our study within the context of state- and institutional-level improvement efforts to support community college student success in STEM and other fields. We then introduce the use of early momentum metrics as leading indicators of collegewide reforms, highlighting the need for better measures of program momentum. We turn to prior empirical and theoretical literature, as well as related work on STEM transfer momentum specifically, to provide conceptual grounding for this study.

1.1 State and Institutional Community College Improvement Efforts

Across the country, community colleges are redesigning programs and support services to improve student success in STEM and other fields. To do so, many have adopted the framework known as guided pathways, an ambitious, whole-institution transformational approach designed to improve how students enter and navigate through programs of study to earn credentials (Bailey et al., 2015). Under the guided pathways framework, colleges engage in the fundamental redesign of programs, practices, and systems across four areas (Bailey et al., 2015). First, colleges organize programs into career-focused "meta-majors" (e.g., health sciences, computers and information technology) and work with employers and university partners to clearly map every program to job and transfer destinations. Second, colleges redesign the student onboarding experience to accomplish two key goals: (1) help all new students explore and understand program and career options and develop a full program plan, and (2) integrate academic support and evidence-based teaching methods into critical introductory courses. Third, colleges empower advisors to monitor students' progress on their plans, provide frequent feedback, and intervene when students need help or want to change course. And fourth, colleges align program learning outcomes with the requirements for success in that program's job and transfer destinations and integrate active and experiential learning throughout programs to engage students in learning that is relevant to their interests and goals. Guided pathways reforms are underway in more than 400 colleges across the country, and, in at least 16 states, these efforts are incentivized by or coordinated as part of state-level reform efforts (Jenkins et al., 2019, 2020; Community College Research Center, 2021).

Preparing students for transfer to a four-year institution is a core mission of many community colleges, and colleges implementing the guided pathways framework have aimed to strengthen transfer outcomes. Among other reforms, colleges have worked on increasing the transferability of community college students' credits to four-year institutions, a key predictor of transfer students' likelihood of completing a bachelor's degree (Monaghan & Attewell, 2015). Indeed, over the past two decades, most states have newly implemented or further developed some type of statewide transfer agreement, which could include a common set of general education requirements across public four-year colleges, a common course numbering system, or a guaranteed transfer policy that automatically admits students into a destination college contingent upon completion of an associate degree (Kisker et al., 2011; Roksa, 2009; Zaragoza, 2021). While research on states' transfer improvement efforts has been limited, it suggests that early efforts did not noticeably improve transfer rates (Anderson et al., 2006; Gross & Goldhaber, 2009; Roksa, 2009). Additional reforms are sorely needed. While about 80% of new, degree-seeking community college entrants nationwide intend to transfer to a four-year college, only about 30% transfer within six years, and fewer than 15% complete a bachelor's degree (Shapiro et al., 2017). And this already underperforming transfer system disproportionately affects Black, Hispanic, and low-income community college students (Shapiro et al., 2017, 2019).

The guided pathways framework suggests that past efforts to improve community college transfer rates may have been hindered by their focus on general education coursework. The conventional wisdom that transfer students should "get their gen eds out of the way" at community college may be flawed because not all transferable gen eds fulfill bachelor's degree program requirements. Fink et al. (2018) highlighted this distinction between credit *transferability* and *applicability*, identifying widespread misalignment of early community college coursework with bachelor's degree requirements even among successful community college transfer students who completed a bachelor's degree. For example, in two state systems, community college transfer students who completed a bachelor's degree graduated with more excess credits above bachelor's degree requirements if they enrolled in higher proportions of introductory coursework at community college and if they had to retake key courses such as college-level math after they transferred. Misalignment of community college transfer coursework with bachelor's degree requirements and the resulting inefficiency in credit transfer have been not only documented as penalizing successful transfers in terms of excess credits and time to completion (Cullinane, 2014; Xu et al., 2017) but also shown to be a key factor in predicting whether community college transfer students will complete a bachelor's degree in the first place (Monaghan & Attewell, 2015).

In contrast to a focus on general education coursework, the guided pathways framework suggests that transfer efforts should focus on helping students explore and connect to fields of interest upon entry at community college. In accordance with the guided pathways framework, more recent community college reforms focus on aligning early coursetaking to baccalaureate programs to ensure students' credits apply to four-year degree requirements (Zaragoza, 2021). In particular, some states have recently moved toward program-level transfer agreements, which apply and expand existing statewide policies in the context of specific programs, such as business, education, or chemistry. Program-level transfer agreements clearly articulate pre-major and transfer-level program requirements agreed upon by institutional leaders across the state, providing students with a roadmap to enter directly into participating four-year institutions with junior standing in their chosen major. Such program-specific agreements can reduce the accrual of unnecessary or excess credits and increase the likelihood of transfer students completing a degree (Baker, 2016; Fink et al., 2018; Fink & Jenkins, 2020). By identifying common, program-specific foundational courses for fields of study across an entire state, community colleges and their primary four-year partners are better equipped to advise students on which early courses will not only transfer but also apply to their bachelor's degree program (Wyner et al., 2016).

1.2 Early Momentum as a Metric for Formative Evaluation

The growing guided pathways reform movement is increasing the demand for practical and timely metrics that colleges can use to understand whether their reforms are on the right track or need redirection. Guided pathways reforms are difficult to evaluate because guided pathways is a whole-college reform model intended to "treat" all students at a college; thus, reformers do not have a clear control group for comparison. Moreover, colleges implementing new reforms cannot afford to wait three years or longer to observe changes in student graduation rates; they need actionable information as early as possible. Thus, many colleges implementing guided pathways have turned to early momentum metrics: simple measures such as student enrollment intensity, continuity, and first-year credit accumulation, which are good predictors of associate degree completion, transfer to a four-year college, and bachelor's degree completion (Attewell & Monaghan, 2016; Belfield et al., 2016, 2019; Wang, 2017). Crucially, these metrics are measurable after only one year, and institutions can evaluate their progress by observing year-over-year trends. Early momentum metrics are key tools in formative assessment of reforms; they not only allow leaders to determine if reforms are resulting in improvements for students generally but also can signal progress toward closing equity gaps if institutions disaggregate metrics across key student subpopulations (Belfield et al., 2019). The predictive power of early academic milestones has been shown to be especially strong for Black, Hispanic, and low-income students (Lin et al., 2020), suggesting that leaders working to close equity gaps in longer-term outcomes should focus their efforts on closing such gaps in the near term.

While early momentum metrics are useful, they do not capture program momentum, or the extent to which students are making progress in their chosen program of study. Wang (2017) has mentioned program momentum as theoretically important to the concept of momentum, but only three empirical studies have explored it. Two studies examined whether community college students entered a program of study within the first year of enrollment, which researchers define as earning nine credits or completing three courses within any specific program area. Jenkins and Cho (2012) showed that community college students who failed to meet this bar were much less likely to transfer and earn a credential. Denley (2016) showed that students in both community colleges and public universities who met this bar were more than twice as likely to complete a college credential in six years than students who did not meet this bar. To measure STEM-specific momentum, Wang (2015) created a measure of first-term "STEM quality points" for community college students, which combines the number of credits accumulated and grades earned in any type of STEM course, finding that these points predict STEM bachelor's degree completion among students intending to transfer into STEM.

From a practical perspective, program momentum may be a more helpful construct than general early momentum for two reasons. First, qualitative researchers have identified students' program of study as a promising focal point for student success reform. In particular, community college programs that have more clearly defined program requirements, stronger program coherence, and integrated academic and nonacademic supports also have substantially stronger performance in terms of student credential attainment and rates of transfer to four-year college (Carey, 2008; Jenkins & Cho, 2014; Scrivener et al., 2012). Second, student success improvement efforts, program-specific or otherwise, are not feasible without the engagement and commitment of program faculty. Yet for faculty who work within specific departments or programs, general institutional metrics may seem abstract or irrelevant to their daily work; in contrast, program- or field-specific metrics may be more meaningful and engaging (Bailey et al., 2015). Thus, inclusion of program-specific measures in addition to general early momentum metrics creates more opportunity for engagement of program faculty in institutional reform efforts.

1.3 STEM Transfer Program Momentum

Improvements in program momentum and completion are of particular concern in the area of STEM transfer. STEM workers are in demand by employers and earn high wages in the labor market, but well-paying and fast-growing jobs in STEM typically require a bachelor's degree (Fayer et al., 2017). Nationally, it is unclear how many STEM bachelor's degree earners start at a community college and follow a transfer pathway.

However, among bachelor's degree graduates overall, nearly half attended a community college at some point, including those who took occasional summer courses or pursued dual enrollment in a community college during high school (National Student Clearinghouse Research Center, 2017). This proportion may be even higher among female, Black, and Hispanic STEM degree holders (Mooney & Foley, 2011; Tsapogas, 2004).

Compared to similar four-year college starters, community college starters are less likely to successfully earn a bachelor's degree in STEM (Hu & Ortagus, 2019; Monaghan & Attewell, 2015; Wang, 2015). Many STEM programs at community colleges are marked by an absence of widely accepted sequences of transferable courses, and major-specific program maps may be nonexistent or infeasible for students to follow, due to a misalignment between the early coursework that some four-year STEM programs demand and the coursework that most community colleges can offer (Bahr et al, 2017; Jaggars et al, 2016). Community college students from relatively privileged backgrounds are more likely to have the financial and social network resources necessary to navigate through such barriers, while traditionally underserved students are more likely to suffer from them (Jabbar et al, 2019; Jaggars et al., 2016; Wang, 2020). However, compared to four-year colleges, community colleges often provide a climate that is more welcoming to women and students of color and thus have the potential to close gaps in STEM achievement for these populations (Hu & Ortagus, 2019; Jackson & Laanan, 2011; Mooney & Foley, 2011; Tsapogas, 2004).

To improve transfer pathways and student performance in STEM, community colleges need measures of momentum that are relevant to these pathways. General early momentum metrics, or even metrics based on general STEM coursetaking, may not be highly relevant to STEM transfer pathways because not all courses within a given program apply to bachelor's degrees in the same area (Bailey et al., 2015; Fink et al., 2018; Lyon & Denner, 2016). (For example, many students take "non-major" versions of biology, chemistry, physics, or other STEM courses as part of their general education requirements, but these courses are not designed to fulfill major-specific requirements for bachelor's degrees in the same fields.)

To measure STEM program momentum, researchers need clear definitions of STEM versus non-STEM courses, an understanding of which STEM courses will transfer to a four-year college, and an understanding of which STEM courses will actually apply toward earning a STEM bachelor's degree. The work of Wang (2016) and Chan and Wang (2020) provide a strong foundation in this regard. First, Wang (2016) used two-digit CIP codes to identify STEM courses and classify those that are "likely transferable" to a four-year college. The limitations of this system of classification are that, even within the category of likely transferable STEM courses, some courses may not actually transfer, grant a student access to a STEM major post-transfer, or apply to the student's STEM bachelor's degree program. Thus, Chan and Wang (2020) further refined the taxonomy by drawing on institutions' transfer articulation agreements to identify courses that are typically transferable and classify them as either foundational (e.g., general physics, general geology) or advanced (e.g., organic chemistry, microbiology).

Using the refined taxonomy, Chan and Wang (2020) found a modest alignment between students' transfer intent and their coursetaking patterns and likelihood of completion. For instance, community college students interested in pursuing a bachelor's degree in a STEM field were more likely to take transferable STEM courses, which in turn improved their likelihood of transfer as well as degree attainment. Wang (2016) used transcript data analysis to show that community college students who ended up being successful in STEM transfer tended to earn more credits in likely transferable STEM courses and fewer credits within other non-STEM categories both in their first year and throughout the six-year window of the study. Yet this approach to identifying transferable STEM courses is incomplete in the context of GP-aligned state and institutional reform efforts, which aim to ensure that courses not only transfer but also apply to each student's bachelor's degree program.

In this paper, we build on prior empirical work in the context of three states in which transfer reforms have led to the creation of statewide STEM-specific transfer pathways. In identifying new measures of STEM transfer momentum, we extend Wang's (2016) concept of likely transferable STEM courses to those that are actually specified on statewide STEM transfer pathways as satisfying STEM baccalaureate degree requirements. In doing so, we advance scholarship around early STEM momentum while also shedding new light on the potential of statewide transfer reforms to improve credit transfer efficiency and transfer student success. We identify and test a set of potential STEM transfer momentum metrics and then compare these against well-established early general academic momentum metrics, concluding with an examination of their usefulness across different types of students and an exploration of their implications for practice.

2. Methodology

2.1 Examining STEM Transfer Pathways in the State Context

Our study focuses on three anonymized states, A, B, and C, that have made progress in implementing program transfer agreements using guided pathways principles. The three states are midsize with between 10 and 40 community colleges in their state system, and each was willing to share its centralized student unit record data for the purposes of this study. For at least the past five years, community colleges in each state have been supported by statewide agencies or associations in implementing student success reforms based on the guided pathways reform framework. Two states (B and C) have had program-level transfer agreements in place for 10 years, while State A more recently began developing program-level agreements that build on a long-standing set of common general education courses, introductory program courses, and course numbering. As a result of these statewide efforts, stakeholders from community colleges and four-year institutions in all three states have established STEM transfer pathways designed to provide community college STEM transfer students with entry into specific STEM majors with junior standing at the state's public (and in some cases private) four-year institutions. Of States A, B, and C, all three have established pathways for biology, chemistry, physics, geology, engineering, and mathematics majors; two have established pathways for computer sciences and information technology majors; and one has an established pathway for agricultural sciences majors. Each transfer pathway includes a set of *specific* lower-division courses that are commonly agreed by public universities and community colleges in each state to fulfill requirements for a bachelor's degree in the given major. Each transfer pathway also provides guidelines for other general education or elective courses that students should take during their first two years at community college in order to enter as a junior in the major at a public university. Typically, pathways are initially developed and periodically updated by discipline-specific faculty work groups including representatives from both two- and four-year institutions, convened by state agencies or other statewide organizations.

For example, in one state, the chemistry major transfer pathway includes the courses Calculus I and II, Calculus-Based Physics I and II with lab, General Chemistry I and II with lab, and Organic Chemistry I and II with lab. Outside of these specific STEM courses, the pathway also provides clear guidelines for selecting additional lower-division courses required to complete a bachelor's degree at any public university (e.g., English Composition I and II, an arts and humanities requirement, a social and behavioral sciences requirement). Transfer pathways may mention, but do not list as requirements, certain institution-specific prerequisites. For example, students who did not take trigonometry or precalculus in high school may need to complete one of these courses prior to enrolling in Calculus I. Similarly, students who did not complete a full year of physics in high school may need to take Algebra-Based Physics before enrolling in Calculus-Based Physics I.

In all three states, the statewide STEM transfer pathways are used as advising guides for transfer-intending community college students and provide clear roadmaps to guaranteed entry into STEM majors after transferring to one of the state's public universities. In the current study, we focus on the STEM courses listed on these transfer pathways as our primary indicators of interest, guided by the hypothesis that increased enrollment in these specific courses early in a student's community college career should predict longer-term outcomes like STEM transfer and bachelor's degree completion.

2.2 Gathering Data

We analyze state-collected administrative records of students who started for the first time in community college with an intent to transfer and complete a bachelor's degree across three state higher education systems, including 70 community colleges and 268,197 students. In States B and C, administrative records are available only for the community college sector; however, State A records also include the public four-year sector. To assess whether our findings on STEM momentum indicators may also be applicable to the outcomes of similar students beginning in the four-year sector, including those students who declare a baccalaureate STEM major, our analysis also includes 56,577 students who began at 26 nonselective regional four-year institutions in State A.[1]

Each state's administrative student record databases include a set of student demographic and other characteristics, term-by-term enrollment records, detailed transcript records, and degree and credential completion records, along with linked National Student Clearinghouse records on enrollments and degree completions nationally. These administrative data include all degree-seeking students who entered a public state college as a first-time student between fall 2010 and summer 2014 and track each student's record for six years after starting college.

2.3 Estimating STEM Transfer Outcomes

Our primary outcome of interest is whether a student earns a bachelor's degree in a STEM field within six years of their first college entry. The STEM designation of a particular field is based on Wang's (2016) classification of two-digit CIP codes, with the most common bachelor's degree STEM CIP codes being 01 (agricultural, animal, plant, veterinary science, and related fields), 03 (natural resources and conservation), 11 (computer and information sciences and support services), 14 (engineering), 26 (biological and medical sciences), 27 (mathematics and statistics), and 40 (physical sciences). In addition to STEM bachelor's degree completion, we also examine non-STEM bachelor's degree completion as a useful standard of comparison to STEM completion.

Because completion of a bachelor's degree requires many years to measure, and relatively few community college students complete a bachelor's degree within six years, in State A we also capture two intermediate outcomes that may occur along a successful path to a STEM bachelor's degree: (1) transfer to a four-year institution and enrollment in a STEM major within three years of initial community college entry, and (2) progress in STEM after transfer and enrollment in a STEM major. For this second intermediate outcome, we assess whether community college entrants who transfer into a STEM major

[1] In an ancillary analysis presented in section 3.4 we also include 127,017 other students who entered a middle-selective four-year institution in State A.

at a four-year institution (intermediate outcome 1) complete nine or more college credits in STEM fields during their first year post-transfer.

2.4 Classifying Early Coursetaking Variables

Drawing on each state's STEM transfer pathways, we build on Wang's (2016) and Chan and Wang's (2020) classification of early community college STEM coursetaking by detailing 10 different types of early community college STEM courses, as summarized in Table 1.

Table 1
Community College STEM Course Typology

Math course type	Definition	Examples
Calculus	Any calculus course	Calculus I/II
Calculus foundation	Any college-level precalculus, trigonometry, geometry, or algebra course	Precalculus Trigonometry/Geometry College Algebra
Statistics	Any college-level statistics course	Introduction to Statistics
Other college-level math	Any other type of college-level math course outside of the categories above	Differential Equations Accounting
Developmental math	Any developmental or remedial math course	Pre-Algebra
STE course type	**Definition**	**Examples**
STE pathway	Specified in statewide transfer agreements as STE course that applies to university STEM major program and enables students to enter university "major-ready" in STEM	Chemistry I/II Biology I/II Physics
STE foundation	College-specific prerequisite course for the STE pathway courses	Intro to Chemistry Intro to Biology Intro to Physics
Other STE, likely transferable	Likely transferable course based on two-digit CIP codes from Wang (2016); not included in pathway or foundation categories	Intro to Computers Nutrition Astronomy
Other STE, likely terminal	Likely terminal (career and technical education) course based on two-digit CIP codes from Wang (2016); not included in pathway or foundation categories	Drafting Information Technology
Any STE	Broad STE definition that includes any of the courses above and all courses with STE CIP codes based on Wang's (2016) classification but excluding math courses	All of the above

Math courses are commonly required for many majors both within and outside of STEM. Within STEM, transfer-level science courses commonly build on skills developed in various math courses; as a result, math and science courses are often taken concurrently or one after another in subsequent semesters. This dual approach to math and science course completion could obfuscate any program-specific findings; if we were to measure STEM coursetaking in general, its predictive power could be due merely to generic math momentum. Thus, our typology of community college STEM coursework organizes courses into separate categories for math and non-math science, technology, and engineering (STE) subjects. We further organize courses according to whether they specifically appear on the state transfer pathway ("pathway") or serve as a prerequisite to such courses ("foundation"). As a result, our typology is built around four key types of STEM courses: pathway math (calculus), pathway non-math (STE pathway), foundational math (calculus foundation), and foundational non-math (STE foundation). The following subsections describe our approach to identifying these types of courses, as well as how we categorize the other types of STEM courses that do not fit into pathway or foundation categories.

Math courses. To classify courses into a math subject area, we first used course CIP codes to derive a preliminary list of all math courses and then conducted a manual inspection of keywords in course titles to ensure courses are accurately classified by domain. Based on our review, we categorize each math course into one of nine topics: calculus, precalculus, trigonometry, geometry, college-level algebra, statistics, other college-level math, or developmental math. Of all math courses we analyze, calculus is the only topic that commonly appears within each state's STEM transfer pathways.

To identify the college-level courses that commonly serve as prerequisites to calculus, we examined a broad selection of community college course catalogs within each state. Although specific prerequisites vary across institutions, within all three states, college algebra, trigonometry, geometry, and/or precalculus are common prerequisites; thus, all instances of courses in these subjects are classified as "calculus foundation."

To avoid conflating calculus foundation courses with non-college-level courses such as Pre-Algebra, we maintain a separate classification for developmental math courses. Finally, we also maintain separate classifications for statistics courses (which commonly appear on non-STEM transfer pathways in each state) and for other college-level math courses. Definitionally, other college-level math includes any college-level course that has a math CIP code but does not fit into any of the prior categories. Such courses may be transferable or not; in general, they are irrelevant to STEM transfer pathways (such as the courses Technical Mathematics or Quantitative Reasoning) or are higher-level courses rarely taken by community college students (such as Differential Equations). Given that the various subtypes within the other college-level math category are relatively uncommon in our dataset, we believe that grouping them together is an appropriate choice for this study.

STE pathway courses. For each state, we identified non-math STE courses that appear on at least one STEM transfer pathway. For example, within one state, Calculus-Based Physics I appears on the physics, chemistry, and math transfer pathways and is thus classified as a STE pathway course for that state. Although the lists of STE pathway courses are similar across the three states, they are not identical. For example, Historical Geology appears on a STEM transfer pathway and is thus classified as a STE pathway course in two states; however, it or a similar course does not qualify as a STE pathway course in the remaining state, so it is not included on the list for that state.

STE foundation courses. Similar to how calculus foundation courses function in relation to calculus courses, STE foundation courses are prerequisites for STE pathway courses. Because prerequisites vary by state and institutional context, the number and type of these courses, though generally similar across contexts, vary as well. For example, some community colleges have multiple prerequisites for a given STE pathway course, while others offer only one prerequisite or none at all. In each state, we examined course catalogs and conducted conversations with state and college informants to identify relevant prerequisites offered by any community college in the state. For example, in one state, Algebra-Based Physics is considered a prerequisite for Calculus-Based Physics at many but not all of the state's community colleges; in that state, all instances of Algebra-Based Physics are classified as STE foundation courses. Often these college-level courses replicate coursework that is commonly offered in high schools but is not always required for high school graduation.

Other STE courses. While the guided pathways framework suggests that courses appearing on STEM transfer pathways are likely to be the most important markers of successful transfer, it may also be important to capture other types of STEM coursetaking. Thus, we used Wang's (2016) identification of likely transferable and likely terminal STEM CIP codes to categorize the remaining non-math STE courses offered in all three states. To ensure we observe any overall relationship between STEM transfer outcomes and early STE coursework—defined in the broadest terms—we created a tenth and final category of STEM coursetaking, any STE, which includes any courses in the STE pathway, STE foundation, and other STE categories.

2.4 Identifying a Simple Set of Predictive Metrics

To explore our first research question—Can a simple set of STEM momentum metrics predict students' long-term transfer outcomes at a similar or superior level as widely used general early momentum metrics?—we first run a series of logistic regression models. As described in Table 2, we group a wide array of potentially useful independent variables into different combinations or "blocks" of predictors. Grouping these variables into different blocks allows us to compare how well different sets of predictors explain variation in each of the longer-term STEM transfer outcomes. In other words, we can compare whether a limited set of STEM momentum metrics explains about the same amount of variation in students' longer-term outcomes as a much more detailed set of STEM momentum metrics. We take this first step in our analysis in order to compare different sets of STEM momentum metrics to general academic momentum metrics and to assess how much additional explanatory power is gained by adding more predictors to the model. The following subsections describe the predictors included in each block.

Table 2
Block Design for Logistic Regression

Block	Description of variables included
General academic momentum[a]	Year 1 average GPA > 3.0 Completed 6+ college-level credits in term 1 Completed 12+ college-level credits in term 1 Year 1 persistence (enrolled in multiple terms) Completed college-level English credits in year 1 Completed 12+ college-level credits in year 1 Completed 24+ college-level credits in year 1
Math momentum	Year 1 college-level math GPA > 3.0 Completed calculus credits in year 1 Completed calculus foundation credits in year 1 Completed statistics credits in year 1 Completed other college-level math credits in year 1 Completed developmental math credits in year 1
STE momentum	Year 1 STE GPA > 3.0 Completed any STE credits in year 1 Completed STE foundation credits in year 1 Completed STE pathway credits in year 1 Completed other STE credits that are likely transferable in year 1 Completed other STE credits that are likely terminal in year 1
Expanded STEM momentum (STE and math momentum)	All variables included in both math momentum and STE momentum blocks
Parsimonious STEM momentum	Completed calculus credits in year 1 Completed calculus foundation credits in year 1 Completed STE foundation credits in year 1 Completed STE pathway credits in year 1
Student demographics	Age, gender, income, race/ethnicity

[a] Credits reported in semester hours were converted and analyzed in equivalent quarter hours where relevant.

General academic momentum, math momentum, and STE momentum blocks. The general academic momentum block includes indicators of general academic momentum from Belfield et al. (2019), and the math momentum and STE momentum blocks focus on potential math-specific or STE-specific indicators. The general academic momentum block includes indicators such as whether students earn at least 6 or 12 credits in their first term, earn at least 12 or 24 credits in their first year, complete college-level English credits in their first year, persist from their first term to second term, and maintain a 3.0 GPA or higher in their first year (Belfield et al., 2019). The math momentum block includes indicators such as whether students complete a math course categorized as calculus, precalculus, trigonometry, or geometry, college-level algebra, developmental math, or statistics, and whether students earn a B or higher GPA in math coursework. The STE momentum block includes indicators such as whether students complete STE pathway courses, STE foundation courses, or other likely transferable or likely terminal STE courses classified with a CIP code taxonomy from Wang (2016), excluding math coursework. In the STE momentum block we also include indicators such as whether students earn a B or higher GPA in their STE coursework.

Expanded and parsimonious STEM momentum blocks. Together, the math momentum, STE momentum, and general academic momentum blocks contain the full array of potentially useful momentum indicators. In order to understand whether a full array is necessary or a more parsimonious array may be as useful, we design two additional blocks. First, the expanded STEM momentum block includes all 12 variables from the math and STE momentum blocks. Second, the parsimonious STEM momentum block includes only four key STEM momentum variables: completion of calculus, calculus foundation, STE pathway, or STE foundation courses. Based on our review of statewide transfer pathways and feedback from state agencies and college faculty and staff, we hypothesize that these four indicators best capture early STEM momentum. In particular, completion of calculus and STE pathway coursework enables students to enter a STEM baccalaureate major after transfer, and thus we expect completion of these two types of early STEM coursework to be most strongly related to STEM transfer outcomes relative to our other indicators. However, students may not have progressed to these more advanced STEM pathway courses in their first year of college; thus, we also include in the parsimonious STEM momentum block prerequisites to calculus and STE pathway courses (i.e., calculus foundation and STE foundation courses).

Demographic indicators. Available student demographic data varies by state but in each state includes at least race/ethnicity, gender, age, and a measure of student/family income (e.g., eligibility for need-based aid).

To explore how well the parsimonious STEM momentum block explains STEM transfer outcomes relative to other blocks with more predictor variables, we construct a series of models predicting six-year bachelor's degree attainment in STEM using different combinations of blocks. The model equations are specified as follows:

$$STEM\ BA\ in\ 6yr_i = \alpha_i + \beta(STEM\ Block\ 3_i) + \gamma(Academic\ Momentum_i) + \delta X_i + \phi_i + \epsilon_i \quad (1)$$

$$STEM\ BA\ in\ 6yr_i = \alpha_i + \beta(STEM\ Block\ 4_i) + \gamma(Academic\ Momentum_i) + \delta X_i + \phi_i + \epsilon_i \quad (2)$$

In these equations, β represents a vector of STEM credit momentum binary indicators for student i (*STEM Block 3* represents all STEM momentum measures while *STEM Block 4* represents the parsimonious set of four STEM momentum measures), γ represents a vector of early academic momentum binary indicators for student i, δ includes controls for student demographics, ϕ represents an institution-by-year fixed effect, and ϵ is an error term clustered at the institution-year level. In State A, parallel models are also conducted with the binary outcomes of transfer into a STEM major and STEM progression post-transfer.

In order to compare the predictive power of different combinations of blocks, we examine pseudo-R^2 as well as visuals of the area under the ROC (Receiving Operating Characteristic) curves (AUC). AUC values range from 0 to 1, with values of .5 and below indicating limited to no predictive power and values of .8 and above indicating acceptable predictive ability (Bowers & Zhou, 2019).

2.5 Examining the Preferred Set of Metrics

Our second research question asks whether a simple set of STEM momentum metrics are reliable (or consistent in their predictive power) across a wide variety of student groups, including those that are historically underrepresented in STEM. Given the broad array of state, institutional, and program contexts under study, it may be that, although preferred metrics are associated with subsequent STEM transfer outcomes overall, there are particular subgroups of students to whom this overall pattern does not apply. If we are able to demonstrate that the parsimonious STEM momentum block provides a good balance between simplicity and predictive power, we will further examine the reliability of these measures in two ways. First, in order to ensure that our findings are not merely artifacts of variation in STEM program quality or performance across institutions or cohorts, we will expand Equation 2 by adding institution-by-year fixed effects to control for cross-institution and cross-year variation. Second, we will take two different approaches (a "conditional" approach and an "interaction" approach) to examine reliability across student gender and race/ethnicity. In the conditional approach, we will model Equation 2 conditional on race/ethnicity or gender to allow comparisons across student subgroups in terms of the predictive power of our parsimonious STEM momentum block. In the interaction approach, we will expand Equation 2 by adding a vector of interaction terms for each of the parsimonious STEM momentum block predictors, in order to test for disproportionate effects for female students and for students from historically underrepresented racial/ethnic groups (Black, Hispanic, Native American, and Pacific Islander).

2.6 Exploring Practical Insights

Our third research question deals with the practical meaning of these metrics. That is, to what extent do these metrics reflect students' intent to study STEM, students' success within STEM, and institution-specific efforts to support STEM pathways?

To explore this question, we first must understand whether these metrics capture students' STEM intent, STEM momentum, or both. Although most community colleges track their students' declared majors, transfer-intending students are typically enrolled in generic majors (e.g., "general transfer"), leaving colleges uncertain about whether a student intends to transfer in STEM. Thus, any predictive power of early community college STEM momentum indicators could be derived primarily from their signaling effect—the indicators' ability to identify STEM transfer-aspiring students. To explore this issue, we take two different approaches in an attempt to disentangle STEM transfer intent and momentum. First, we examine the predictive power of our preferred STEM momentum indicators if we require only that students attempt, rather than complete, these courses in their first year. Earlier work on general academic momentum suggests that even *attempting* more credits is associated with stronger college outcomes (Attewell et al., 2012). Furthermore, attempting a course, such as a calculus or STE pathway course, may represent an equivalent signal of student intent to transfer into STEM as completing that same course. Second, we draw on samples of entrants at nonselective public four-year colleges in State A, for whom we can observe STEM bachelor's degree major intent. We compare the predictive power of the preferred STEM momentum metrics versus the declaration of a STEM major among this sample of four-year entrants. We further extrapolate this comparison to the community college population in the same state by testing the reliability of findings among a sample of community college students who are matched to peers at nonselective four-year colleges who declared a STEM major.

Finally, we use our preferred STEM momentum metrics to understand the extent to which colleges are helping students gain STEM transfer momentum during the period under study. To do so, we provide descriptive information regarding variation across community colleges, as well as disparities by gender and race/ethnicity, to get a sense of whether colleges are helping students complete key STEM courses and gain STEM transfer momentum.

2.7 Identifying Limitations

Our analysis makes use of information recorded in statewide administrative data systems, which do not provide data on precollege factors that influence academic outcomes, such as high school performance measures and high school attended. While our logistic regression analysis and ensuing robustness checks are high powered, the lack of an experimental or quasi-experimental design prevents us from making causal claims. Our analysis is correlational: We ask which readily available early indicators can *predict* students' outcomes, with the understanding that these proximal indicators and the ultimate outcomes of interest may be mutually influenced by other student-level and institutional-level factors.

Another limitation of our study is a lack of information regarding community college student majors. As noted earlier, community college students who intend to transfer are typically enrolled in generic majors such as "general transfer." Our propensity score matching analysis shows that early STEM momentum metrics capture more than just STEM intent; however, we could likely improve upon our preferred model's predictive power if we had more robust data on community college students' major intent.

Finally, although we work carefully to connect courses to statewide pathways, we may not always accurately categorize STEM courses. It is particularly challenging to identify course prerequisites; these courses are not designated on statewide pathways, which contributes to an astonishing degree of variation in STEM prerequisite structures and course titles across the 70 community colleges and 26 non-selective four-year institutions included in this study. As a result, some courses that should belong in the STE foundation category may be erroneously classified as other STE, likely transferable.

3. Results

3.1 Sample

Tables 3 and 4 present descriptive results on the demographic characteristics of our student sample in each state as well as the independent variables included in the general academic and STEM momentum blocks. In students' first year at community college (CC), between 36% and 43% of students complete any non-math STE college-level coursework, while between 19% and 34% of students complete any college-level math coursework. The most commonly completed STEM courses are those in the category of other STE, likely transferable, while the least commonly completed STEM courses are those in the category of other STE, likely terminal. The proportion of students completing non-math STE foundation or pathway courses varies across states but remains below 10% in each state included in our sample. Only 7% of students in State A, where four-year institutional data are available, transfer into a STEM major within three years of starting at community college. In State A, among students who transfer into STEM, 63% accumulate nine or more STEM credits in their first year post-transfer. Overall, STEM bachelor's completion rates are low for community college starters, with no state in our sample exceeding 4% among all entering transfer-intending students (although between 8% and 18% of students complete a bachelor's degree in a non-STEM field).

Table 3
Sample Characteristics

Student characteristics	State A, CC entrants (*N* = 92,679)	State A, NSFY entrants (*N* = 56,577)	State B, CC entrants (*N* = 50,890)	State C, CC entrants (*N* = 124,628)
Gender				
Male	48%	45%	44%	52%
Female	52%	55%	56%	48%
Race/ethnicity				
Asian	2%	1%	2%	12%
Black	22%	12%	20%	6%
Native/American Indian	1%	< 1%	< 1%	1%
Hispanic	4%	2%	4%	3%
Pacific Islander	< 1%	< 1%	< 1%	< 1%
White	64%	77%	70%	55%
Other/Unknown	7%	7%	4%	15%
Age upon entry				
20 and under	64%	73%	68%	60%
21–24	17%	11%	12%	16%
25+	19%	17%	19%	24%
Entering cohort				
2010–11 AY	27%	27%	26%	27%
2011–12 AY	26%	26%	26%	26%
2012–13 AY	25%	24%	25%	23%
2013–14 AY	22%	23%	23%	24%

Table 4
Outcomes and Momentum Indicators

	State A, CC (*N* = 92,679)	State A, NSFY (*N* = 56,577)	State B, CC (*N* = 50,890)	State C, CC (*N* = 124,628)
Outcomes				
STEM bachelor's completion	3%	3%	1%	4%
Non-STEM bachelor's completion	15%	18%	8%	15%
Transfer into STEM major	7%			
Persistence in STEM in first year post-transfer (among those who transfer into STEM)	63%			
General academic momentum				
Year 1 average GPA > 3.0	36%	31%	26%	38%
Completed 6+ CL credits in term 1	48%	62%	49%	62%
Completed 12+ CL credits in term 1	17%	26%	20%	25%
Year 1 persistence (enrolled in multiple terms)	75%	78%	82%	66%
Completed CL English in year 1	47%	56%	45%	44%
Completed 12+ CL credits in year 1	48%	59%	41%	53%
Completed 24+ CL credits in year 1	23%	33%	16%	26%
Math momentum in year 1				
Year 1 CL math GPA > 3.0	44%	39%	42%	46%
Completed any CL math credits	24%	34%	19%	23%
Completed calculus credits	4%	5%	1%	6%
Completed any calculus foundation credits	16%	25%	10%	9%
Completed calculus foundation credits: precalculus	2%	3%	3%	9%
Completed calculus foundation credits: trigonometry or geometry	2%	5%	<1%	<1%
Completed calculus foundation credits: CL algebra	12%	17%	6%	2%
Completed statistics credits	4%	4%	8%	5%
Completed other CL math credits	6%	8%	7%	5%
Completed developmental math credits	34%	30%	15%	37%
STE momentum in year 1				
Year 1 STE GPA > 3.0	45%	38%	45%	46%
Completed any STE credits	36%	43%	26%	29%
Completed any STE foundation credits	5%	4%	2%	6%
Completed any STE pathway credits	6%	8%	6%	3%
Completed other STE credits, likely transferable	33%	42%	25%	26%
Completed other STE credits, likely terminal	4%	2%	1%	2%

3.2 Predictive Power of STEM Momentum Metrics

Our first research question asks whether a simple set of STEM momentum metrics can predict students' long-term outcomes at a similar or superior level as widely used general early momentum metrics. In order to explore that question, Tables 5 and 5a provide the pseudo R^2 for each of our logistic regression models, with Table 5 focusing on six-year STEM bachelor's degree completion and Table 5a focusing on the intermediate outcomes in State A. As expected, explanatory power increases substantially as we move from including only a single block to including multiple blocks in the same model. However, the parsimonious STEM momentum block, comprising only four math and science coursetaking momentum indicators, explains an equivalent or slightly larger amount of variation when compared to general academic momentum, math momentum, or STE momentum blocks.

Table 5
Logistic Regression Model Summary, STEM Bachelor's Degree Completion

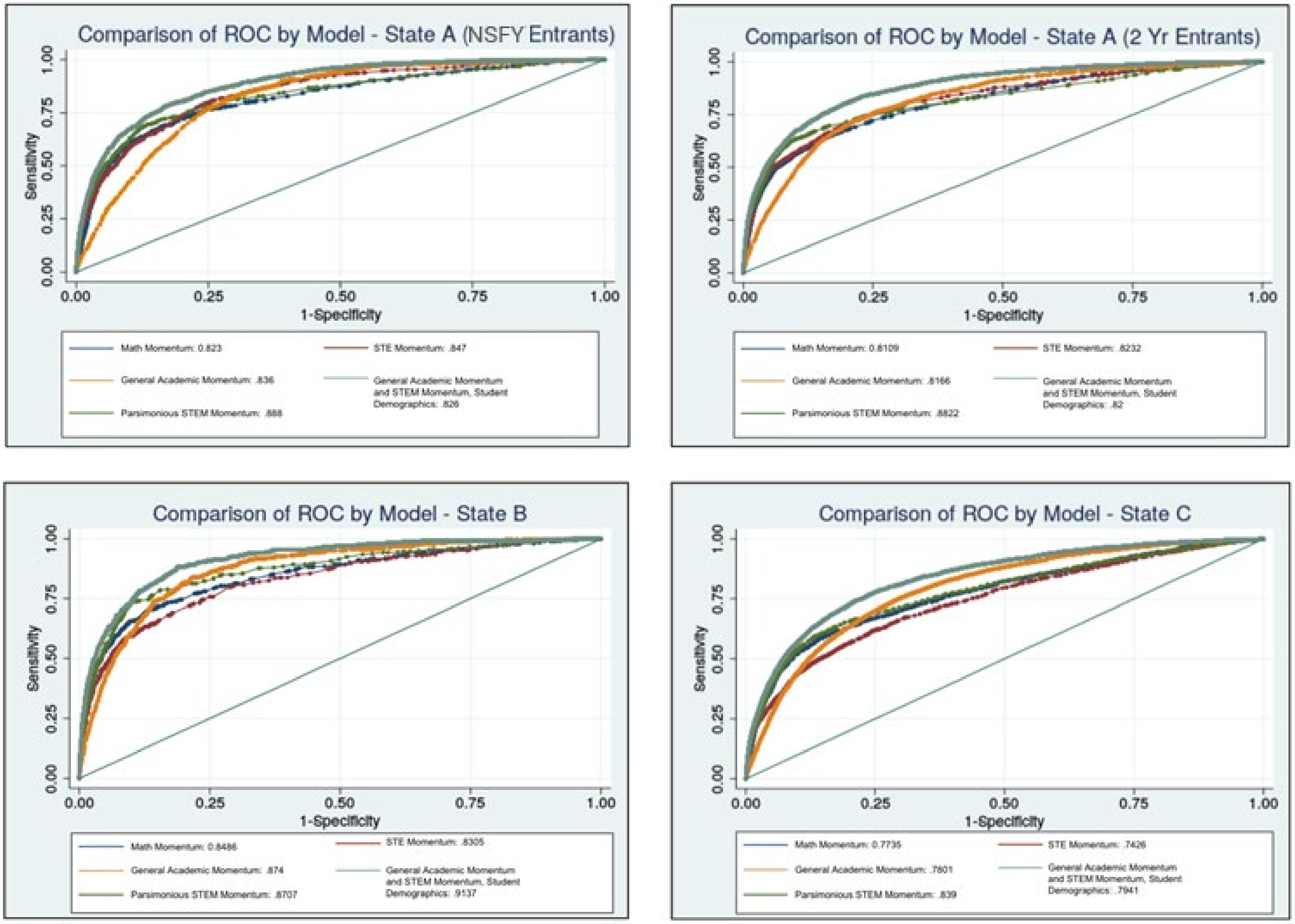
	Pseudo R^2 (observations)			
Variable blocks	State A, CC	State A, NSFY	State B, CC	State B, CC
Math momentum	.187 (91,894)	.193 (56,137)	.203 (50,607)	.147 (123,668)
STE momentum	.203 (91,929)	.213 (56,150)	.175 (50,607)	.119 (123,668)
Parsimonious STEM momentum	.216 (91,929)	.216 (56,150)	.215 (50,607)	.151 (123,668)
Expanded STEM momentum (blocks 1 and 2 combined)	.257 (91,894)	.269 (56,137)	.247 (50,607)	.182 (123,668)
General academic momentum	.160 (91,890)	.163 (56,138)	.188 (50,607)	.135 (123,668)
General academic and STEM momentum	.273 (91,882)	.286 (56,132)	.266 (50,607)	.207 (123,668)
General academic and STEM momentum, student demographics	.295 (91,835)	.299 (54,506)	.283 (50,607)	.223 (123,668)

Table 5a
State A, Community College Entrants:
Logistic Regression Model Summary, Intermediate STEM Transfer Outcomes

	Pseudo R^2 (observations)	
Variable blocks	Transfer into STEM major	STEM progression post-transfer
Math momentum	.163 (92,642)	.246 (92,481)
STE momentum	.181 (92,679)	.263 (92,517)
Parsimonious STEM momentum	.209 (92,679)	.301 (92,517)
Expanded STEM momentum (blocks 1 and 2 combined)	.235 (92,642)	.343 (92,481)
General academic momentum	.120 (92,638)	.199 (92,477)
General academic and STEM momentum	.242 (92,630)	.359 (92,469)
General academic and STEM momentum, student demographics	.292 (92,583)	.392 (92,422)

Figure 1 presents AUC values for each model in Table 5. Across states and models, AUC values range from approximately .8 to .9 and are highest for the full model that includes general academic, math, and STE momentum and demographic variable blocks. While there is variation in AUC values across states and models, their relative stability and high level suggest that all the models—including the model containing only the parsimonious STEM momentum block—are reliably strong predictors of STEM bachelor's degree completion for community college entrants in all states, as well as for four-year entrants in State A. Similar AUC results (not shown) are observed for the models in Table 5a.

Figure 1
AUC Values for Each Model Block by State (STEM Bachelor's Degree Completion)



The R^2 and AUC results suggest that the four indicators included in the parsimonious STEM momentum block are jointly useful in explaining STEM bachelor's degree completion. To explore the practical descriptive power of these four predictors (and how they compare to the other potential predictors), Table 6 shows the descriptive relationship between early STEM coursetaking and STEM bachelor's degree completion. While only between 1% and 4% of students in our full sample complete a STEM bachelor's degree within six years of entering community college, those who complete a STE pathway or calculus course in their first year have substantially higher rates of STEM bachelor's completion, particularly in States A and C. For example, among students in State C who complete a STE pathway course in their first year at community college, 25% complete a STEM bachelor's degree within six years. We observe heterogeneity across states in the relationship between degree completion and calculus or STE pathway course completion in students' first year, with State B having substantially lower rates of STEM bachelor's completion, both conditional on meeting these metrics and overall. However, calculus or STE pathway course completion is still among the strongest descriptive predictors of STEM bachelor's completion in State B.

While completing a calculus or STE pathway course is a clear predictor of longer-term STEM transfer success, this is less clear for calculus foundation and STE foundation courses. Descriptively, in each state, completion of a calculus foundation course seems to be a more useful indicator of STEM bachelor's completion than any of the general academic momentum metrics alone, albeit less useful than completion of calculus or STE pathway credits. However, in each state, completing a *specific* calculus foundation course may be an equivalent or better predictor than completing *any* calculus foundation course. For example, in States A and B, completing precalculus credits may be a more useful descriptive indicator, while in State C, completing trigonometry or geometry credits may be more useful. Completion of a STE foundation course is a relatively weak descriptive predictor compared to the other three parsimonious indicators; however, it performs reasonably well in comparison to general academic momentum indicators.

Further corroborating findings from the regression analyses, descriptive results presented in Table 6 suggest that early STEM indicators—particularly calculus and STE pathway credit completion and to a lesser degree calculus and STE foundation credit completion—have a stronger relationship with STEM bachelor's degree completion than do general measures of academic momentum. Taken together, these findings suggest that the parsimonious set of four STEM momentum metrics are generally suitable as leading indicators of longer-term STEM outcomes across the state samples.[2] In subsequent analyses, we examine the reliability of this parsimonious set of four STEM indicators across institutions, entry cohorts, and student demographic subgroups.

Table 6
STEM Bachelor's Degree Completion Rates Conditional on First-Year Coursetaking Metrics

Characteristic	Six-year STEM bachelor's completion rate			
	State A, CC (*N* = 92,679)	State A, NSFY (*N* = 56,577)	State B, CC (*N* = 50,890)	State C, CC (*N* = 124,628)
All students	3%	3%	1%	4%
General academic momentum				
Year 1 average GPA > 3.0	6%	7%	2%	7%
Completed 6+ CL credits in term 1	5%	5%	1%	4%
Completed 12+ CL credits in term 1	10%	8%	3%	2%
Year 1 persistence (enrolled in multiple terms)	4%	4%	1%	4%
Completed CL English credits in year 1	4%	4%	1%	5%
Completed 12+ CL credits in year 1	6%	5%	2%	5%
Completed 24+ CL credits in year 1	9%	8%	3%	6%
STEM momentum in year 1				

[2] As a check on this interpretation, we also examine whether these four STEM momentum indicators are generally predictive of earning any bachelor's degree rather than a STEM bachelor's degree. Across all samples, we find that the four STEM momentum metrics are generally weak predictors of completion of non-STEM bachelor's degrees, with most individual coefficients being not significant. That is, the STEM momentum indicators appear to be precise in capturing early STEM program momentum; they predict subsequent transfer success in STEM but not in non-STEM.

Completed calculus credits	26%	23%	14%	23%
Completed any calculus foundation credits	16%	12%	4%	11%
Completed calculus foundation credits: precalculus	17%	15%	9%	11%
Completed calculus foundation credits: trigonometry or geometry	14%	10%	4%	15%
Completed calculus foundation credits: CL algebra	6%	5%	2%	10%
Completed any STE foundation credits	7%	9%	3%	9%
Completed any STE pathway credits	24%	18%	6%	25%

Note. This table reports rates of STEM bachelor's completion within six years of beginning in college, conditional on students' first-year course completions. Credit thresholds are reported as semester-system equivalents.

3.3 Reliability of STEM Momentum Indicators

Our second research question asks whether our preferred metrics are reliably useful across a wide variety of student groups, including those that are historically underrepresented in STEM. First, we examine reliability across institutions and entry cohorts; next, we examine reliability across gender and race/ethnicity.

Reliability across institutions and entry cohorts. Table 7 presents results from a series of logistic regression models that examine how well each of the four parsimonious STEM momentum indicators predicts subsequent STEM bachelor's completion net of other general academic momentum indicators, student demographics, and differences observed by institution and entry year. In particular, we focus on Model 3, which includes institution-by-year fixed effects alongside other controls to test the reliability of the four STEM momentum indicators across unobservable differences based on the college or cohort year in which students begin their journey toward a STEM bachelor's degree.

While coefficients for each of the four indicators attenuate from Model 1 to Model 3 within each state, they appear to be more stable for STE pathway and calculus course completion. For instance, in State A, the coefficients for STE pathway course completion attenuate only slightly across models from roughly .05 to .04; for State A four-year colleges, the coefficient for calculus course completion also drops only slightly across models from about .04 to .03.

After controlling for demographic, institutional, and cohort fixed effects in Model 3, in States A and C the coefficient estimates for STE pathway and calculus course completion range from .02 to .04 and are consistently statistically significant at $p < .001$. These results suggest that early completion of a STE pathway or calculus course in these states is associated with a two- to four-percentage point increase in the likelihood of attaining a STEM bachelor's degree within six years of entry. While these single digit percentage point increases may seem small, they represent a meaningful increase given that only between 1% and 4% of students in the sample transfer and complete STEM bachelor's degrees overall. In State B, coefficient estimates for STE pathway and calculus course completion appear slightly less strong but remain positive and statistically significant. Thus, in general, STE pathway or calculus course completion appears to be a useful predictor of STEM bachelor's degree attainment regardless of state, institutional, or cohort contexts.

Consistent with the descriptive results presented in Table 6, coefficients in Table 7 for STE and calculus foundation course completion are weaker than for STE pathway and calculus course completion. In some models and states, the foundation indicator coefficients are weakly positive and significant, while in others, they are estimated as near zero. Thus, while STE or calculus foundation course completion has some general predictive value, it may be less useful within certain state and institutional contexts.

Table 7
Regression Estimates From Predictive Models of First-Year Coursetaking on Six-Year STEM Bachelor's Degree Completion

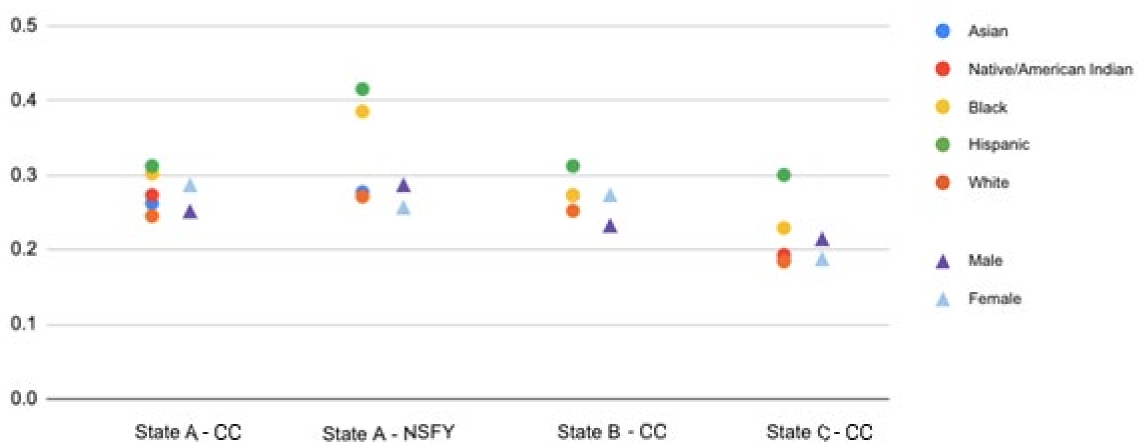
	State A, CC			State A, NSFY			State B, CC			State C, CC		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Completed STE pathway credits in Y1	0.051***	0.040***	0.039***	0.046***	0.037***	0.036***	0.013***	0.010***	0.010***	0.043***	0.040***	0.041***
	(0.001)	(0.001)	(0.012)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Completed STE foundation credits in Y1	0.007***	0.001	0.000	0.012***	0.009***	0.010***	0.006***	0.004***	0.004***	0.008***	0.008***	0.008***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Completed calculus credits in Y1	0.046***	0.029***	0.024***	0.045***	0.033***	0.030***	0.013***	0.009***	0.008***	0.059***	0.038***	0.037***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Completed calculus foundation credits in Y1	0.018***	0.003*	0.002	0.027***	0.019***	0.018***	0.010***	0.005***	0.006***	0.027***	0.015***	0.016***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	92,679	90,567	90,411	56,577	56,565	54,510	50,890	50,890	50,607	124,628	124,628	123,668
Academic controls			X			X			X			X
Demographic controls		X	X		X	X		X	X		X	X
Institution & cohort fixed effects		X	X		X	X		X	X		X	X

Note. Standard errors in parentheses.

***p < .001. **p < .01. *p < .05.

Reliability across race/ethnicity and gender. In Table 7, Model 2 controls for demographic characteristics such as race/ethnicity and gender, demonstrating that the four parsimonious STEM indicators are still statistically significant predictors of STEM bachelor's degree completion after controlling for these characteristics. To explore potential heterogeneity in the predictive power of STEM momentum metrics across race/ethnicity and gender, Figure 2 presents the pseudo R^2 values derived from Equation 2 conditioned on different student racial/ethnic and gender groups by state. In each state, the R^2 values for historically underrepresented groups are similar to or better than the R^2 values for White or male students, suggesting that the four parsimonious STEM indicators are indeed predictive for historically underrepresented students.

Figure 2
R^2 Value of Parsimonious STEM Momentum Block by Race/Ethnicity and Gender



As an additional check, we test for disproportionate effects for historically underrepresented students by expanding Equation 2 with a vector of interaction terms by gender ("FEM") and historically underrepresented students of color ("HU"), including Black, Hispanic, Native American, or Pacific Islander students (see Appendix Table A1). In general, the results suggest that the four STEM momentum metrics are reliable across race/ethnicity and gender. While there are a few statistically significant interactions across the four indicators, they do not form a consistent pattern. A few interactions in State A imply that the STEM momentum metrics may have slightly more predictive power for women. In only one case does an interaction effect nullify or reverse the direction of the main effect for a parsimonious indicator: In State C, after taking into account a significant and negative interaction effect, the relationship between STE foundation coursework and STEM bachelor's completion is erased and even dips into negative territory for historically underrepresented students of color. To further understand this relationship, more exploration closer to practice is needed, including an investigation of inequities in student referral to STE foundation courses and availability of STE pathway courses.

To further describe the relationship between key early STEM course completion and longer-term STEM bachelor's degree completion, Table 8 reports STEM bachelor's completion rates for students who complete each of the four parsimonious STEM momentum metrics in their first year, disaggregated by race/ethnicity and gender. Although students who gain early STEM momentum (i.e., complete one of the parsimonious STEM momentum metrics) across race/ethnicity and gender subgroups have higher STEM bachelor's completion rates compared to students who do not gain early STEM momentum, equity gaps by race/ethnicity and gender are present—both in early STEM momentum rates and in STEM bachelor's completion rates even among students who do gain early STEM momentum. In general, male and Asian students have higher STEM bachelor's degree completion rates than their peers, a pattern that is apparent across the four metrics. For example, among community college students in State A who complete a STE pathway course in their first year, 27% of men eventually earn a STEM bachelor's degree, compared to 20% of women.

Table 8
Six-Year STEM Bachelor's Degree Completion Rates, by First-Year STEM Coursetaking and Student Characteristics

	Completed STE pathway credits in Y1				Completed STE foundation credits in Y1			
	State A, CC	**State A, NSFY**	**State B, CC**	**State C, CC**	**State A, CC**	**State A, NSFY**	**State B, CC**	**State C, CC**
All students	24%	18%	6%	25%	7%	9%	3%	9%
Gender								
Male	27%	22%	9%	29%	12%	15%	4%	13%
Female	20%	15%	4%	19%	3%	4%	1%	6%
Race/ethnicity								
Asian	30%	30%	9%	31%	14%	19%	4%	14%
Black	16%	19%	5%	14%	4%	7%	<1%	3%
Native/American Indian	17%	30%	<1%	7%	4%	< 1%	<1%	2%
Hispanic	22%	14%	8%	28%	8%	4%	2%	3%
Pacific Islander	14%	20%		13%	< 1%	25%		< 1%
White	25%	18%	6%	24%	7%	8%	3%	9%
Other/unknown	15%	15%	3%	21%	4%	15%	<1%	8%

	Completed calculus credits in Y1				Completed calculus foundation credits in Y1			
	State A, CC	**State A, NSFY**	**State B, CC**	**State C, CC**	**State A, CC**	**State A, NSFY**	**State B, CC**	**State C, CC**
All students	26%	23%	14%	23%	16%	12%	4%	11%
Gender								
Male	27%	26%	15%	25%	16%	15%	6%	13%
Female	25%	18%	10%	20%	15%	9%	3%	9%
Race/ethnicity								
Asian	32%	27%	15%	22%	19%	16%	6%	11%
Black	23%	29%	7%	23%	13%	15%	3%	7%
Native/American Indian	38%	50%	<1%	4%	11%	14%	<1%	6%
Hispanic	29%	24%	15%	21%	19%	5%	6%	12%
Pacific Islander	33%	25%		24%	< 1%	25%		6%
White	27%	23%	14%	25%	16%	12%	4%	12%
Other/unknown	10%	17%	21%	24%	9%	8%	4%	11%

3.4 Practical Meaning of Momentum Metrics

Our third research question delves into the practical meaning of our preferred metrics by investigating the extent to which these metrics reflect students' intent to study STEM versus their success within STEM, as well as by exploring the extent to which colleges help students gain STEM transfer momentum.

Signaling intent, capturing momentum, or both? Thus far, our findings suggest that early completion of key STEM courses specified on statewide community college STEM transfer pathways is a robust and reliable indicator of subsequent STEM transfer success. While it could be that completion of these courses indicates STEM momentum among students aspiring to transfer into STEM majors at four-year institutions, it may also be that completion of these courses simply indicates which students intend to transfer into STEM majors at four-year institutions. To help understand the extent to which our momentum metrics actually measure intent for STEM transfer, we first examine the predictive power of our preferred STEM momentum indicators if we require only that students *attempt* (rather than *complete*) these courses in their first year. We then test our STEM momentum indicators among subsamples of students who almost certainly do intend to pursue a STEM bachelor's degree.

First, we re-run the models in Table 5, replacing each of our four parsimonious STEM indicators with an attempt of each relevant course rather than a completion of the course. If the four indicators were merely capturing STEM transfer intent, we would expect to observe as strong of a relationship between *attempting* these courses and earning a STEM bachelor's degree as for *completing* these courses and earning a STEM bachelor's degree. When re-running our results using course attempts, we find that individual coefficient predictors attenuate but remain positive and statistically significant. These findings suggest that the STEM momentum metrics may indeed capture intent but also capture student STEM momentum above and beyond their role as a proxy of STEM transfer intent.

Second, we work to further disentangle intent from momentum by testing our STEM momentum indicators among subsamples of students who almost certainly intend to pursue a STEM bachelor's degree.[3] In State A, our dataset includes students who enter a public university as a freshman, where students declare a specific major such as chemistry, biology, or STEM exploration. We limit this analysis to students at nonselective and middle-selective public universities, excluding those that are more selective, in order to focus on students who are more comparable to community college populations. In Table 9, we re-run the models from Table 7 for the nonselective and middle-selective four-year (MSFY) entrants in State A, with the addition of an indicator for whether students ever declared a STEM major as a predictor and the inclusion of general academic momentum, demographic, and institution-by-cohort fixed effect controls. The STEM momentum indicators, particularly completion of a calculus or STE pathway course, retain their significance as predictors of STEM bachelor's completion even after controlling for whether students ever declared a STEM major (which unsurprisingly is also a strong predictor).

Table 9
State A, Nonselective and Middle-Selective Four-Year College Entrants: Estimates From Predictive Models of First-Year Coursetaking on Six-Year STEM Bachelor's Degree Completion

	NSFY entrants			MSFY entrants		
Variable	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Completed calculus credits	.030*** (.002)		.017*** (.002)	.071*** (.002)		.028*** (.001)
Completed calculus foundation credits	.018*** (.002)		.002 (.001)	.049*** (.002)		.005** (.001)
Completed STE pathway credits	.036*** (.002)		.010*** (.003)	.118*** (.002)		.021*** (.001)
Completed STE foundation credits	.010*** (.002)		.004 (.002)	.066*** (.002)		.015*** (.002)
Declared a STEM major		.105*** (.003)	.094*** (.003)		.317*** (.004)	.286*** (.004)
Pseudo R^2	.282	.469	.484	.316	.546	.558
Observations	56,138	56,138	56,138	127,394	127,394	127,394

Note. Standard errors in parentheses. All models include academic and demographic controls, as well as institution-by-cohort fixed effects.

$^{***}p < .001$. $^{**}p < .01$. $^{*}p < .05$.

[3] In addition to analyses involving four-year college entrants, we also re-run the models in Tables 5 and 7 in all three states using subsamples of transfer-intending community college entrants who signal potential intent to complete a STEM bachelor's degree by attempting a calculus foundation course (precalculus, trigonometry, or college algebra) in their first year. Results show that the four STEM momentum indicators, notably completion of a calculus or STE pathway course, remain strong predictors and have even larger individual coefficients predicting longer-term STEM bachelor's completion than those shown in Table 7.

In order to further explore how these findings may apply to STEM-intending students in the community college population, we employ propensity score matching to select a subsample of community college peers who are similar to nonselective and middle-selective four-year STEM majors (in terms of available precollege variables in our dataset, including demographic characteristics and precollege dual enrollment coursetaking, such as whether the student took a math or science course as part of their dual enrollment experience). We use Mahalanobis matching to adjust for pretreatment observable differences and test for overlap between treated (started at a nonselective or middle-selective four-year college) and control (started at a community college) groups. The results suggest strong balance and common support,[4] reinforcing our identification of STEM majors at nonselective or middle-selective four-year colleges as reasonable comparison groups for the matched community college samples. As shown in Table 10, we re-run a logistic regression model of STEM bachelor's completion in six years on our parsimonious STEM momentum indicators as well as general academic momentum, demographic, and institution-by-cohort fixed effect controls; however, in this instance, we limit our sample to community college students who match to nonselective and middle-selective four-year STEM majors in our propensity score analysis. Table 10 shows that coefficients for completion of calculus and STE pathway courses remain positive among those community college students who are matched with nonselective and middle-selective four-year STEM majors.[5]

[4] None of the covariates in our model have a matched standardized difference above .05 in absolute value, and almost all of our covariates have a ratio of standard deviations between 0.95 and 1.05.

[5] In additional checks, we re-run the propensity score analysis while dropping treated observations with a higher or lower propensity score than the minimum or maximum propensity score of the control group and also limit the sample of matched community college students to those who attempted a calculus foundation course in their first year. In both types of checks, the four STEM momentum indicators, particularly completion of a calculus or STE pathway course, remain significant predictors of STEM bachelor's degree attainment.

Table 10
Regression Estimates on Six-Year STEM Bachelor's Degree Completion for Matched Community College Students

Matched subgroup	Calculus	Calculus foundation	STE pathway	STE foundation
State A community college entrants matched to peers who declare STEM majors at **nonselective** four-year institutions	.017 (.014)	-.017 (.014)	.031** (.011)	.013 (.016)
State A community college entrants matched to peers who declare STEM majors at **middle-selective** four-year institutions	.056** (.020)	-.013 (.017)	.085*** (.015)	.001 (.020)

Note. Standard errors in parentheses. All models control for general academic momentum, other STEM momentum metrics, and demographic variable blocks as well as institution-by-cohort fixed effects. The sample for these regressions is limited to STEM-intending community college students in State A who match with similar nonselective and middle-selective four-year STEM majors.

***$p < 0.001$. **$p < 0.01$. *$p < 0.05$.

These results suggest that the four STEM momentum metrics do capture an element of STEM bachelor's degree intent and also capture the extent to which STEM-intending students are progressing along the pathway toward that destination. The examination of four-year college students in State A also allows us to revisit descriptive results from Table 4 with more information about STEM intent. Table 11 presents the four STEM momentum metrics for nonselective and middle-selective four-year college entrants, disaggregated by STEM major intent, as well as for their matched peers at community colleges. Columns 2 and 4 of Table 11 confirm our intuition that four-year STEM majors are much more likely than four-year non-STEM majors to complete any of the four STEM indicators in their first year. For example, among nonselective four-year entrants, 15% of STEM majors complete a calculus course in their first year, compared to 3% of non-STEM majors.

Column 1 of Table 11 shows STEM momentum metrics for the 7% of community college students who are similar to nonselective four-year college STEM majors in terms of our limited array of precollege characteristics, including dual enrollment math and science coursetaking. The propensity score matching algorithm's suggestion that these community college students may be STEM-intending is bolstered by these students' levels of STE foundation and pathway coursetaking, which are substantially higher than the overall levels shown in Table 4. Indeed, these students' STEM momentum metrics are similar to or higher than those of their nonselective four-year STEM-intending peers, implying that for STEM-intending students in State A, community colleges may support initial STEM coursetaking just as well as (or even better than) nonselective four-year colleges.

However, the story is quite different for the 12% of community college students matched with middle-selective four-year college STEM majors (column 3). Compared to their peers in STEM majors at middle-selective four-year institutions (column 4), these community college students are just as or more likely to complete a calculus foundation course; however, they are much less likely to complete a calculus course or any STE foundation or pathway courses.

Table 11
State A, Public Two- and Four-Year College Entrants: First-Year STEM Coursetaking

	(1) CC (*N* = 92,679)	(2) NSFY (*N* = 56,577)		(3) CC (*N* = 92,679)	(4) MSFY (*N* = 127,407)	
	Matched to NSFY STEM majors	STEM majors	Non-STEM majors	Matched to MSFY STEM majors	STEM majors	Non-STEM majors
Proportion of sample	7%	18%	82%	12%	25%	75%
Among this subsample						
Completed calculus credits	20%	15%	3%	30%	40%	11%
Completed calculus foundation credits	40%	36%	19%	35%	32%	19%
Completed STE pathway credits	30%	24%	5%	40%	53%	10%
Completed STE foundation credits	7%	6%	4%	10%	21%	3%

How well are colleges helping students gain STEM momentum? In order to explore how well community colleges are helping students gain STEM momentum, we describe STEM momentum metrics across demographic groups, states, and individual colleges. Results presented earlier in this paper (see Table 4) suggest that large percentages of students are completing likely transferable STEM coursework, but relatively few are completing the specific courses laid out on their state's STEM transfer pathways—that is, the courses that are most predictive of successful STEM transfer and bachelor's completion.

To examine momentum metrics across types of students, Table 12 disaggregates the four parsimonious STEM momentum metrics by gender and race/ethnicity, revealing that gaps between demographic groups already appear by the first year of community college. For example, Table 12 shows that Asian students are substantially more likely than other racial/ethnic groups to complete STE pathway, calculus, and calculus foundation courses in their first year at community college. Disparities across gender are less pronounced, although male students complete STE pathway, calculus, and calculus foundation courses at slightly higher rates across states compared to female students.

Table 12
First-Year STEM Coursetaking by Student Gender and Race/Ethnicity

	Completed STE pathway credits in Y1				Completed STE foundation credits in Y1			
	State A, CC	State A, NSFY	State B, CC	State C, CC	State A, CC	State A, NSFY	State B, CC	State C, CC
All students	6%	9%	6%	4%	5%	4%	2%	6%
Gender								
Male	6%	10%	7%	4%	4%	4%	2%	5%
Female	5%	8%	5%	3%	6%	5%	2%	6%
Race/ethnicity								
Asian	14%	25%	9%	7%	7%	5%	4%	8%
Black	2%	4%	2%	2%	3%	4%	1%	5%
Native/American Indian	3%	5%	7%	2%	5%	5%	1%	4%
Hispanic	5%	10%	6%	2%	4%	5%	2%	3%
Pacific Islander	6%	8%	7%	2%	4%	6%	1%	5%
White	7%	9%	7%	3%	6%	5%	3%	6%
Other/unknown	4%	6%	3%	3%	3%	3%	1%	5%

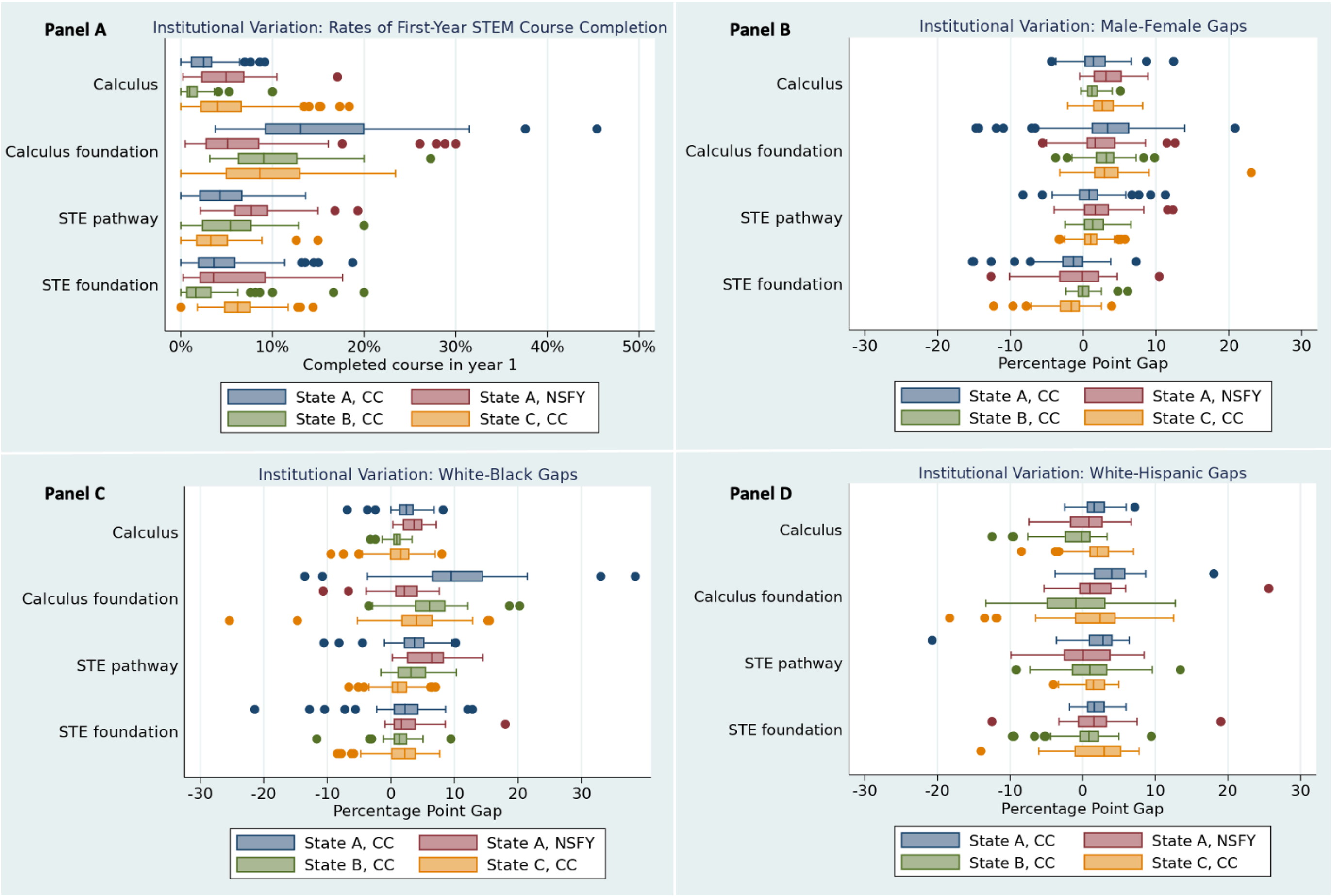
	Completed calculus credits in Y1				Completed calculus foundation credits in Y1			
	State A, CC	State A, NSFY	State B, CC	State C, CC	State A, CC	State A, NSFY	State B, CC	State C, CC
All students	4%	5%	1%	6%	4%	9%	10%	9%
Gender								
Male	6%	7%	2%	7%	5%	9%	11%	11%
Female	3%	4%	1%	6%	3%	6%	8%	9%
Race/ethnicity								
Asian	12%	19%	6%	16%	9%	12%	19%	17%
Black	1%	2%	1%	3%	2%	6%	4%	6%
Native/American Indian	2%	3%	1%	2%	2%	7%	10%	5%
Hispanic	3%	5%	3%	2%	3%	6%	12%	5%
Pacific Islander	3%	6%	<1%	2%	2%	7%	9%	8%
White	5%	6%	2%	4%	5%	8%	11%	9%
Other/unknown	4%	7%	1%	3%	3%	5%	7%	8%

Table 12 also suggests that the three states vary slightly in terms of the proportion of community college students who achieve each type of metric. In terms of STE courses, community colleges in States A and B seem to push a higher proportion of students to quickly enter transfer-level STE courses laid out on state pathways, while community colleges in State C seem to push the completion of STE foundation courses. Within each state, however, individual colleges' performance on each metric varies widely (see Figure 3, Panel A). In these box and whisker plots, boxes represent the interquartile range (from 25th to 75th percentile), the line in the middle displays the median value, and the whiskers show the range of values adjacent to the outside values (shown as dots). Panel A displays each institution's overall performance on each metric, while the remaining panels examine institutional performance through an equity lens, with Panel B displaying gaps by gender (male-female) and Panels C and D displaying gaps by race/ethnicity (White-Black and White-Hispanic, respectively).

In general, Figure 3 reveals a strong degree of variation across colleges within a given state. For example, in State C, only 6% of community college students complete a calculus course in their first year, yet at a handful of colleges in the state, 15–20% of students do so. More importantly from an equity perspective, some colleges show startlingly large gaps in STE pathway or calculus course completion by gender or race/ethnicity. Yet other colleges show no gaps or even negative gaps (i.e., *stronger* results for women, or for Black or Hispanic students). The differences by college observed in overall rates of STE pathway and calculus course completion, as well as the variation in disparities between student groups, point to a need for more investigation into policies and practices at individual colleges to understand why some are more effective at helping students gain early STEM momentum than others.

Figure 3

Institutional Variation in First-Year STEM Course Completion Rates and Gaps by Student Gender and Race/Ethnicity



Note. Figures present the distribution of first-year course completion rates for each college within a given state. Top left panel (A) shows rates for all students, and the three other panels (B, C, and D) display percentage point gaps, calculated by subtracting rates for female, Black, and Hispanic students from rates for male and White students, respectively.

4. Discussion

This paper uses transcript and student outcome data on cohorts of community college entrants in three states to identify, validate, and describe metrics that are useful for college leaders looking to formatively assess efforts to improve STEM program outcomes, with a particular focus on students underrepresented in STEM, as part of broader guided pathways reforms. In general, our results affirm previous findings on the relationship between general early momentum measures and college completion (Attewell & Monaghan, 2016; Belfield et al., 2016, 2019; Wang, 2017). However, these general early momentum measures are less useful predictors of STEM transfer and bachelor's degree completion than STEM-specific measures of early momentum.

Across all the indicators we examine, first-year completion of calculus or other specific types of STEM courses—those designated by each state as required to achieve junior standing within a four-year STEM major—is an especially strong and reliable early indicator of STEM transfer and bachelor's completion. In State A, for example, only 3% of all transfer-intending community college students completed a STEM bachelor's degree within six years; but among those who completed a STE pathway course in their first year, 24% completed a STEM bachelor's degree. The strength of these indicators is consistent across demographic groups, as well as across a wide variety of contexts (including cohorts, types of institutions, and states). However, few students take these courses in their first year, and there are widespread equity gaps by race/ethnicity and gender.

4.1 Scaffolding Foundational and Transfer Pathway Courses

Our results suggest that completing any of four specific types of STEM courses in the first year of community college predicts eventual bachelor's degree attainment in STEM: (1) calculus courses, which consistently appear on statewide STEM transfer pathways, (2) the courses that serve as a foundation for calculus (e.g., Precalculus, Trigonometry), (3) STE pathway courses that appear on statewide transfer pathways for specific majors (e.g., Chemistry I), and (4) STE foundation prerequisites for those courses (e.g., Introduction to Chemistry). However, the predictive power of calculus and

STE pathway courses is substantially stronger and more consistent than that of their prerequisite foundation courses.

Foundational STEM courses often consist of coursework that could be completed at the high school level, such as trigonometry or a full-year sequence of introductory chemistry, but are inconsistently required of high school students to earn a diploma and may not be offered by all high schools. Community colleges receive a steady stream of STEM-intending students who have either not recently completed high school or not completed such foundational coursework in high school. As a result, colleges typically place these students into a series of preparatory courses. For example, in two of the states under study, prerequisites to transfer-level biology and chemistry include at least three separate preparatory subject courses. Although these courses do earn students college-level credit, in many ways the foundational STEM track is analogous to the traditional developmental math and English system—a system that a large body of research finds to be ineffective at helping students who are underprepared in these subjects move forward toward graduation, with disproportionate effects on low-income students and students of color (Chen & Simone, 2016; Jaggars & Bickerstaff, 2018).

With this context in mind, STEM departments such as physics, chemistry, or biology may find it helpful to learn about college mathematics reforms that accelerate the academic momentum of students who arrive at college underprepared in math. These reforms reduce or eliminate prerequisite developmental math coursework and allow students to immediately enroll in more challenging math courses such as Statistics or College-Level Algebra, while providing learning supports that are tailored specifically to helping students gain and practice the skills needed to be successful in the course (Braithwaite et al., 2020). Successful acceleration efforts typically include both curricular and instructional reform. From a curricular perspective, prerequisite sequences can be shortened by removing content that is repetitive or unnecessary for success in the subsequent course or can be redesigned into corequisite courses that provide just-in-time instruction and practice for challenging concepts. From an instructional perspective, students can outperform expectations in math courses that focus on student collaboration, active student thinking and discussion, the grounding of problems in real-world contexts to develop conceptual understanding, and explicit attention to students' organizational and study habits (Bickerstaff & Edgecombe, 2019; Zachry Rutschow et al., 2019; Wang et al., 2021).

In general, developmental reform efforts do not focus on STEM-intending students; most reforms in developmental mathematics aim to help non-STEM-intending students fulfill degree requirements in quantitative reasoning, statistics, or college-level algebra (Brathwaite et al., 2020). For students bound for calculus and calculus-heavy STEM courses, only one reform effort has been well documented: the Dana Center Mathematics Pathway (DCMP), which has been deployed across multiple community colleges in Texas (Zachry Rutschow et al., 2019). For STEM-intending students, DCMP colleges teach a two-course Reasoning with Functions sequence that replaces the traditional College-Level Algebra and Precalculus sequence. Although the Functions approach does not shorten the prerequisite sequence for calculus, its curriculum and instruction are tailored to helping students master and become confident in the mathematics concepts and skills needed in STEM disciplines; for example, students use functions to model and solve meaningful problems in science, technology, and engineering.[6]

In addition to rethinking their prerequisite sequences, STEM departments can also encourage and assist underserved students to take College-Level Algebra and other foundational STEM coursework in high school by offering these courses through dual enrollment programs. For example, one rigorous study in Florida found that among high school students who were at the margin of eligibility for dual enrollment College-Level Algebra, taking the course improved the likelihood that they would enroll in college and enter a STEM major; these findings were particularly strong for Black and Hispanic students (Minaya, 2021).

Finally, in order to connect incoming students to appropriate coursework and supports, community colleges need to identify students who are interested in STEM majors early on. As part of the guided pathways reform framework, many community colleges have reorganized individual programs into broad fields of study, or "meta-majors" (e.g., business, health, or STEM), which has enabled reforms of traditional new

[6] For more detailed information about the DCMP Reasoning with Functions courses, see Dana Center Mathematics Pathways (n.d.-a, n.d.-b).

student orientation to better identify students who, for example, aspire to transfer into a STEM program at a four-year institution. By identifying in students' first year which broad fields of study they intend to pursue, community colleges are better equipped to connect them to courses, faculty mentors, and other experiences to help build early program momentum (Jenkins et al., 2020).

4.2 Increasing Equity of Access for State Transfer Pathways

Community colleges seeking equitable access and outcomes for their students should consider what other systemic challenges might contribute to low and inequitable rates of transfer-level STEM course completion and how the implementation of state transfer pathways can support success for all students. While the positive relationship between early STEM coursework and longer-term STEM transfer outcomes is fairly consistent across our results, much work remains to ensure access to and adequate support for all college students who wish to attempt STEM coursework, no matter where they begin their college journey. Table 12 demonstrates the stark disparities in first-year STEM coursetaking between student racial/ethnic groups; Asian and White students are more likely in all states to complete a STE pathway course in their first year at community college than Black, Hispanic, and Native American students. It also demonstrates how these disparities can compound over time; within the context of a prerequisite sequence for science and math courses, Asian and White students are also more likely to earn credits in foundational math and STE courses in their first year, increasing the rate of their momentum toward transfer and four-year degree completion over other student groups.

An additional consideration for colleges seeking to improve access to and success in state STEM transfer pathways is the availability of calculus, calculus foundation, STE pathway, and STE foundation courses each term. A supplementary analysis of the availability of STE pathway and foundation courses in our sample finds that most courses offered by term in key STE subject areas (e.g., biology, chemistry, and physics) are not the courses specified on statewide STEM transfer pathways. For example, in State B, STE pathway courses account for 24% of the biology courses offered at community colleges in fall 2018, and STE foundation courses account for only 12% of the biology courses offered. A similar pattern emerges in State C, where calculus courses comprise

16% of college-level math courses offered by community colleges in fall 2019, and calculus foundation courses account for 21% of college-level math courses. These supplementary analyses raise further questions, such as: What are the other types of STEM courses that students are taking, and toward what programs do those courses count?

4.3 Identifying Areas for Future Research

Our analyses raise a number of additional questions for future research. First, the college-by-college variation in rates of early STEM momentum raises further questions around why some colleges are more effective at helping students gain early STEM momentum. What can be learned from colleges that are doing better in this area, particularly from colleges that are more effective in increasing STEM momentum for women and students of color? Second, our analysis treats course types (e.g., STE pathway) as uniform, but within each type of course, there is surely variation in how students experience the course content. Future research can examine how much of the predictive power of early STEM coursework is due to its specific topic and how much is due to other factors related to the classroom dynamic, such as the instructor or course composition. For example, within a specific course such as Chemistry I, to what extent do sections of the course vary in terms of how well women and students of color succeed in (and beyond) the course?

Finally, each state in our study has developed transfer pathways in other areas, such as business, nursing, or education. Would our methodological framework—identifying courses specified on the given state's transfer pathway—work equally as well in operationalizing program momentum in other disciplines? In particular, our analysis finds that both the key STEM math courses (calculus) as well as key non-math STEM courses (STE pathway courses) are similar in their relationship to longer-term STEM outcomes. Perhaps any program's momentum involves two elements—program-relevant math and other (non-math) program-relevant content. Or perhaps in other subjects, general but highly important content courses in areas such as English or history might play a similar role to math within STEM. In general, extensions of the program momentum framework can examine the relative importance of program-specific courses versus program-critical (but not program-specific) courses such as math and English.

5. Conclusion

In this study, we examine postsecondary college transcript and degree records from hundreds of thousands of college students across dozens of colleges in three states to explore and test metrics that may be useful for community college leaders to formatively assess their college's efforts to improve STEM transfer outcomes. We find that a relatively simple set of STEM momentum metrics—notably early completion of calculus or STE coursework included in statewide STEM transfer pathways and, to a lesser degree, the prerequisites to these courses—are reliable indicators of subsequent STEM transfer success across the wide-ranging state and institutional contexts observed in this study. We also find that these metrics are robust predictors among subgroups of students by race/ethnicity and gender. Yet community college students have relatively low rates of completion of these key STEM courses, and disparities in completion of these courses by race/ethnicity and gender are common. Low and inequitable rates of STEM transfer and bachelor's completion can be traced back to low and inequitable rates of early STEM momentum. Some colleges are more effective than others in correcting for these inequities and in helping more students gain early STEM momentum, and the variation we observe across institutions implies that improvement on these key early indicators is indeed possible. The STEM momentum metrics identified in this paper offer promising utility in the formative assessment of community college reforms aimed at strengthening STEM transfer outcomes and closing equity gaps in STEM bachelor's attainment.

References

American Association of Community Colleges. (2021). *Fast facts 2021*. https://www.aacc.nche.edu/research-trends/fast-facts/

Attewell, P., Heil, S., & Reisel, L. (2012). What is academic momentum? And does it matter? *Educational Evaluation and Policy Analysis, 34*(1), 27–44. https://doi.org/10.3102/0162373711421958

Attewell, P., & Monaghan, D. (2016). How many credits should an undergraduate take? *Research in Higher Education, 57*(6), 682–713. https://doi.org/10.1007/s11162-015-9401-z

Anderson, G., Sun, J. C., & Alfonso, M. (2006). Effectiveness of statewide articulation agreements: A preliminary policy analysis. *The Review of Higher Education, 29*(3), 261–291. https://doi.org/10.1353/rhe.2006.0001

Bahr, P. R., Jackson, G., McNaughtan, J., Oster, M., & Gross, J. (2017). Unrealized potential: Community college pathways to STEM baccalaureate degrees. *The Journal of Higher Education, 88*(3), 430–478. https://doi.org/10.1080/00221546.2016.1257313

Bailey, T. R., Jaggars, S. S., & Jenkins, D. (2015). *Redesigning America's community colleges: A clearer path to student success*. Harvard University Press.

Baker, R. (2016). The effects of structured transfer pathways in community colleges. *Educational Evaluation and Policy Analysis, 38*(4), 626–646. https://doi.org/10.3102/0162373716651491

Belfield, C., Jenkins, D., & Fink, J. (2019). *Early momentum metrics: Leading indicators for community college improvement*. Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/early-momentum-metrics-leading-indicators.html

Belfield, C., Jenkins, D., & Lahr, H. (2016). *Momentum: The academic and economic value of a 15-credit first-semester course load for college students in Tennessee* (CCRC Working Paper No. 88). Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/momentum-15-credit-course-load.html

Bowers, A. J., & Zhou, X. (2019). Receiver operating characteristic (ROC) area under the curve (AUC): A diagnostic measure for evaluating the accuracy of predictors of education outcomes. *Journal of Education for Students Placed at Risk (JESPAR)*, *24*(1), 20–46. https://doi.org/10.1080/10824669.2018.1523734

Bickerstaff, S., & Edgecombe, N. (2019). *Teaching matters and so does curriculum: How CUNY Start reshaped instruction for students referred to developmental* mathematics (CCRC Working Paper No. 110). Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/teaching-curriculum-cuny-start-developmental-mathematics.html

Brathwaite, J., Fay, M. P., & Moussa, A. (2020). *Improving developmental and college-level mathematics: Prominent reforms and the need to address equity* (CCRC Working Paper No. 124). Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/improving-developmental-college-level-mathematics.html

Carey, K. (2008). *Graduation rate watch: Making minority student success a priority*. Education Sector. https://immagic.com/eLibrary/ARCHIVES/GENERAL//EDSCTRUS/E080418C.pdf

Chan, H.-Y., & Wang, X. (2020). Reconciling intent with action: Factors associated with the alignment between transfer intent and coursework completion patterns among two-year college students in STEM. *The Journal of Higher Education, 91*(7), 1087–1115. https://doi.org/10.1080/00221546.2020.1740533

Chen, X., & Simone, S. (2016). *Remedial coursetaking at U.S. public 2- and 4-year institutions: Scope, experiences, and outcomes* (NCES 2016-405). National Center for Education Statistics. https://nces.ed.gov/pubs2016/2016405.pdf

Community College Research Center. (2021). *Investing in student success at community colleges: Lessons from research on guided pathways.* https://ccrc.tc.columbia.edu/publications/policy-brief-guided-pathways.html

Cullinane, J. P. (2014). *The path to timely completion: Supply- and demand-side analyses of time to bachelor's degree completion* [Doctoral dissertation]. https://repositories.lib.utexas.edu

Dana Center Mathematics Pathways. (n.d.-a). *DCMP reasoning with functions I: Overview and learning outcomes.* https://dcmathpathways.org/resources/dcmp-reasoning-functions-i-overview-and-learning-outcomes

Dana Center Mathematics Pathways. (n.d.-b). *DCMP reasoning with functions II: Overview and learning outcomes.* https://dcmathpathways.org/resources/dcmp-reasoning-functions-ii-overview-and-learning-outcomes

Denley, T. (2016, October). *Choice architecture, academic foci and guided pathways* [PowerPoint slides]. Presentation to the AACC Pathways Institute. https://www.aacc.nche.edu/wp-content/uploads/2017/10/ChoiceArchitectureAcademicFociGuided_TristanDenley.pdf

Fayer S., Lacey A., & Watson A. (2017). *STEM occupations: Past, present, and future*. U.S. Bureau of Labor Statistics. https://www.bls.gov/spotlight/2017/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future/home.htm

Fink, J., Jenkins, D., Kopko, E., & Ran, F. X. (2018). *Using data mining to explore why community college transfer students earn bachelor's degrees with excess credits* (CCRC Working Paper No. 100). Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/using-data-mining-explore-why-community-college-transfer-students-earn-bachelors-degrees-excess-credits.html

Fink, J., & Jenkins, D. (2020). *Unpacking program enrollments and completions with equity in mind*. Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/unpacking-program-enrollments-completion-equity.html

Gross, B., & Goldhaber, D. (2009). *Community college transfer and articulation policies: Looking beneath the surface*. University of Washington, Center on Reinventing Public Education. https://www.crpe.org/publications/community-college-transfer-and-articulation-policies-looking-beneath-surface

Hu, X., & Ortagus, J. C. (2019). A national study of the influence of the community college pathway on female students' STEM baccalaureate success. *Community College Review, 47*(3), 242–273. https://doi.org/10.1177/0091552119850321

Jabbar, H., McKinnon-Crowley, S., & Serrata, C. (2019). Complex pathways to transfer: A qualitative comparative analysis of the transition from community college to 4-year university. *AERA Open, 5*(2). https://doi.org/10.1177/2332858419852039

Jackson, D. L., & Laanan, F. S. (2011). The role of community colleges in educating women in science and engineering. *New Directions for Institutional Research, 2011*(*152*), 39–49. https://doi.org/10.1002/ir.407

Jaggars, S. S., Fink, J., Fletcher, J., & Dundar, A. (2016). *A longitudinal analysis of community college pathways to computer science bachelor's degrees*. Google Inc. http://goo.gl/Eiz33G

Jaggars, S. S., & Bickerstaff, S. (2018). Developmental education: The evolution of research and reform. In M. B. Paulsen (Ed.), *Higher education: Handbook of theory and research* (vol. 33, pp. 469–503). Springer.

Jenkins, D., & Bailey, T. (2017). *Early momentum metrics: Why they matter for college improvement* (CCRC Brief No. 65). Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/early-momentum-metrics-college-improvement.html

Jenkins, D., & Cho, S.-W. (2012). *Get with the program: Accelerating community college students' entry into and completion of programs of study* (CCRC Working Paper No. 32). Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/get-with-the-program.html

Jenkins, D., & Cho, S.-W. (2014). Get with the program . . . and finish it: Building guided pathways to accelerate student learning and success. *New Directions for Community Colleges, 2013*(164), 27–35. https://doi.org/10.1002/cc.20078

Jenkins, D., Lahr, H., Brown, A. E., & Mazzariello, A. (2019). *Redesigning your college through guided pathways: Lessons on managing whole-college reform from the AACC Pathways Project.* Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/redesigning-your-college-guided-pathways.html

Jenkins, D., Lahr, H., & Pellegrino, L. (2020). *Redesigning community college student onboarding through guided pathways, Part 1: Rethinking new student onboarding*. Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/redesigning-community-college-onboarding-guided-pathways.html

Kisker, C. B., Wagoner, R. L., & Cohen, A. M. (2011). *Implementing statewide transfer & articulation reform: An analysis of transfer associate degrees in four states* (Report No. 11-1). Center for the Study of Community Colleges. https://www.asccc.org/sites/default/files/Implementing_Statewide_Transfer_and_Articulation_Reform_2011.pdf

Lin, Y., Fay, M. P., & Fink, J. (2020). *Stratified trajectories: Charting equity gaps in program pathways among community college students* (CCRC Working Paper No. 126). Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/stratified-trajectories-program-pathways.html

Lyon, L. A., & Denner, J. (2016). Student perspectives of community college pathways to computer science bachelor's degrees. Google Inc. https://goo.gl/Q0wJJv

Minaya, V. (2021). *Can dual enrollment algebra reduce racial/ethnic gaps in early stem outcomes? Evidence from Florida*. Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/dual-enrollment-algebra-stem-outcomes.html

Monaghan, D. B., & Attewell, P. (2015). The community college route to the bachelor's degree. *Educational Evaluation and Policy Analysis, 37*(1), 70–91. https://doi.org/10.3102/0162373714521865

Mooney, G. M., & Foley, D. J. (2011). *Community colleges: Playing an important role in the education of science, engineering, and health graduates* (NSF 11-317). National Science Foundation, National Center for Science and Engineering Statistics. https://wayback.archive-it.org/5902/20181003221732/https://www.nsf.gov/statistics/infbrief/nsf11317/

National Student Clearinghouse Research Center. (2017). *Contribution of two-year public institutions to bachelor's completions at four-year instituions* (Snapshot Report). https://nscresearchcenter.org/wp-content/uploads/SnapshotReport26.pdf

Riegle-Crumb, C., King, B., & Irizarry, Y. (2019). Does STEM stand out? Examining racial/ethnic gaps in persistence across postsecondary fields. *Educational Researcher, 48*(3), 133–144. https://doi.org/10.3102/0013189X19831006

Roksa, J. (2009). Building bridges for student success: Are higher education articulation policies effective? *Teachers College Record, 111*(10), 2444–2478. https://www.tcrecord.org/Content.asp?ContentId=15716

Scrivener, S., Weiss, M. J., & Sommo, C. (2012). *What can a multifaceted program do for community college students? Early results from an evaluation of Accelerated Study in Associate Programs (ASAP) for developmental education students*. MDRC. https://www.mdrc.org/publication/what-can-multifaceted-program-do-community-college-students

Shapiro, D., Dundar, A., Huie, F., Wakhungu, P. K., Yuan, X., Nathan, A., & Hwang, Y. (2017*). Tracking transfer: Measures of effectiveness in helping community college students to complete bachelor's degrees* (Signature Report No. 13). National Student Clearinghouse Research Center. https://nscresearchcenter.org/tracking-transfer/

Shapiro, D., Ryu, M., Huie, F., Liu, Q., & Zheng, Y. (2019). *Completing college: 2019 national report* (Signature Report No. 18), National Student Clearinghouse Research Center. https://files.eric.ed.gov/fulltext/ED605984.pdf

Tsapogas, J. (2004) *The role of community colleges in the education of recent science and engineering graduates* (NSF 04-315). National Science Foundation. https://wayback.archive-it.org/5902/20150627182834/http://www.nsf.gov/statistics/infbrief/nsf04315/

Wang, X. (2015). Pathway to a baccalaureate in STEM fields: Are community colleges a viable route and does early STEM momentum matter? *Educational Evaluation and Policy Analysis, 37*(3), 376–393. https://doi.org/10.3102/0162373714552561

Wang, X. (2016). Course-taking patterns of community college students beginning in STEM: Using data mining techniques to reveal viable STEM transfer pathways. *Research in Higher Education, 57*(5), 544–569. https://link.springer.com/article/10.1007%2Fs11162-015-9397-4

Wang, X. (2017). Toward a holistic theoretical model of momentum for community college student success. In M. B. Paulsen (Ed.), *Higher education: Handbook of theory and research* (vol. 32, pp. 259–308). Springer.

Wang, X. (2020). *On my own: The challenge and promise of building equitable STEM transfer pathways*. Harvard Education Press.

Wang, X., Lee, Y., Zhu, X., & Ozdemir, A. O. (2021). Exploring the relationship between community college students' exposure to math contextualization and educational outcomes. *Research in Higher Education*. https://doi.org/10.1007/s11162-021-09644-w

Wyner, J., Deane, K. C., Jenkins, D., & Fink, J. (2016). *The transfer playbook: Essential practices for two- and four-year institutions.* The Aspen Institute College Excellence Program and Columbia University, Teachers College, Community College Research Center. https://ccrc.tc.columbia.edu/publications/transfer-playbook-essential-practices.html

Xu, D., Jaggars, S. S., Fletcher, J., & Fink, J. (2017). Are community college transfer students "a good bet" for 4-year admissions? Comparing academic and labor-market outcomes between transfer and native 4-year college students. *The Journal of Higher Education, 89*(4), 478–502. https://doi.org/10.1080/00221546.2018.1434280

Zachry Rutschow, Sepanik, S., Deitch, V., Raufman, J., Dukes, D., & Moussa, A. (2019). *Gaining ground: Findings from the Dana Center Mathematics Pathways impact study.* Center for the Analysis of Postsecondary Readiness. https://postsecondaryreadiness.org/gaining-ground-dana-center-mathematics-pathways/

Zaragoza, D. (2021). *The state of state transfer policy: A typology to evaluate transfer and recognition of learning policies*. HCM Strategists. http://hcmstrategists.com/resources/the-state-of-state-transfer-policy-a-typology-to-evaluate-transfer-and-recognition-of-learning-policies/

Appendix

Table A1
Logit Model Coefficients on STEM Bachelor's Degree Completion, Including Interaction Terms for Historically Underrepresented Groups

Variables	STEM Momen-tum Metric	State A, NSFY	State A, CC	State B, CC	State C, CC
Completed 6+ credits in term 1		0.012**	0.002	-0.000	-0.001
		(0.005)	(0.002)	(0.002)	(0.002)
Completed 12+ credits in Term 1		0.001	0.002	0.001	-0.011***
		0.012**	(0.002)	(0.002)	(0.002)
Completed 12+ credits in Y1		0.033***	0.024***	0.003	0.008***
		(0.007)	(0.003)	(0.002)	(0.003)
Completed 24+ credits in Y1		0.026***	0.012***	0.001	0.003
		(0.003)	(0.002)	(0.002)	(0.002)
Completed CL math credits in Y1			0.015***	0.001	0.017***
			(0.002)	(0.001)	(0.002)
Completed CL English credits in Y1		-0.007***	-0.008***	0.003	-0.001
		(0.002)	(0.002)	(0.002)	(0.002)
Persisted from term 1 to term 2		-0.007	-0.003	0.002	-0.024***
		(0.007)	(0.003)	(0.003)	(0.003)
GPA of 3.0+ in Y1		0.019***	0.018***	0.009***	0.036***
		(0.002)	(0.002)	(0.001)	(0.002)
Completed STE pathway credits Yr1	X	0.030***	0.034***	0.010***	0.039***
		(0.002)	(0.002)	(0.001)	(0.002)
Completed STE foundation credits in Y1	X	0.011***	0.001	0.006***	0.007***
		(0.003)	(0.002)	(0.002)	(0.002)
Completed calculus credits in Y1	X	0.029***	0.021***	0.009***	0.034***
		(0.002)	(0.002)	(0.001)	(0.002)
Completed calculus foundation credits in Y1	X	0.018***	-0.002	0.005***	0.015***
		(0.002)	(0.002)	(0.001)	(0.002)
Age		-0.001***	-0.000**	-0.000	-0.001***
		(0.000)	(0.000)	(0.000)	(0.000)
Female		-0.002	-0.000	-0.002	-0.022***
		(0.008)	(0.004)	(0.004)	(0.003)
HU_Completed 6+ credits in term 1		0.008	-0.010*	0.006*	-0.002
		(0.013)	(0.005)	(0.004)	(0.006)
HU_Completed 12+ credits in term 1		-0.006	0.007	0.001	-0.019**
		(0.007)	(0.005)	(0.003)	(0.008)
HU_Completed 12+ credits in Y1		0.010	-0.008	-0.004	-0.008
		(0.017)	(0.007)	(0.004)	(0.011)
HU_Completed 24+ credits in Y1		-0.007	0.007	-0.003	0.015**
		(0.008)	(0.005)	(0.003)	(0.007)
HU_Completed CL math credits in Y1		0.006	0.014**	0.002	0.018*
		(0.008)	(0.007)	(0.004)	(0.010)

Variables	STEM Momen-tum Metric	State A, NSFY	State A, CC	State B, CC	State C, CC
HU_Completed CL English credits in Y1		0.004	0.002	-0.003	0.007
		(0.008)	(0.004)	(0.003)	(0.006)
HU_Persisted from term 1 to term 2		-0.012	-0.021***	-0.003	0.003
		(0.015)	(0.006)	(0.004)	(0.010)
HU_GPA of 3.0+ in Y1		0.005	-0.001	-0.001	-0.011*
		(0.008)	(0.005)	(0.003)	(0.006)
HU_Completed calculus credits in Y1	X	0.007	0.004	0.000	-0.000
		(0.007)	(0.005)	(0.003)	(0.008)
HU_Completed calculus foundation credits in Y1	X	0.006	-0.002	0.005	-0.008
		(0.006)	(0.006)	(0.003)	(0.008)
HU_Completed statistics credits in Y1		0.010	-0.005	-0.004	-0.010
		(0.011)	(0.007)	(0.004)	(0.010)
HU_Completed other CL math credits in Y1		-0.006	-0.014**	0.001	-0.030**
		(0.010)	(0.006)	(0.004)	(0.012)
HU_Completed dev. ed. math credits in Y1		0.006	-0.005	0.004	-0.006
		(0.008)	(0.005)	(0.004)	(0.006)
HU_Math GPA of 3.0+ in Y1		0.007	-0.003	0.001	0.012*
		(0.007)	(0.005)	(0.003)	(0.008)
HU_Completed STE pathway credits in Y1	X	0.005	-0.008*	-0.005	-0.010
		(0.007)	(0.005)	(0.003)	(0.009)
HU_Completed STE foundation credits in Y1	X	-0.002	0.009	-0.009	-0.026***
		(0.009)	(0.006)	(0.008)	(0.010)
HU_Cd. other likely transferable STE credits in Y1		0.037	0.032**	0.005	0.013
		(0.023)	(0.013)	(0.010)	(0.009)
HU_Completed other likely CTE STE credits in Y1		0.043***	0.027***	-0.000	-0.054**
		(0.015)	(0.008)	(0.006)	(0.025)
HU_Completed any STE credits in Y1		-0.028	-0.018	-0.001	0.009
		(0.024)	(0.014)	(0.010)	(0.010)
HU_STE GPA of 3.0+ in Y1		0.000	0.002	0.003	0.007
		(0.007)	(0.005)	(0.003)	(0.007)
FEM_Completed 6+ credits in term 1		-0.005	0.006	0.000	-0.001
		(0.008)	(0.004)	(0.003)	(0.003)
FEM_Completed 12+ credits in term 1		-0.001	-0.006**	0.002	0.004
		(0.004)	(0.003)	(0.003)	(0.004)
FEM_Completed 12+ credits in Y1		-0.015	-0.009	0.001	-0.003
		(0.011)	(0.006)	(0.004)	(0.005)
FEM_Completed 24+ credits in Y1		-0.001	0.006*	-0.001	-0.009***
		(0.005)	(0.004)	(0.003)	(0.004)
FEM_Completed CL math credits in Y1		0.005	-0.009**	0.001	0.007
		(0.004)	(0.004)	(0.003)	(0.005)
FEM_Completed CL English credits in Y1		0.001	-0.006**	-0.005*	0.002
		(0.004)	(0.003)	(0.003)	(0.003)
FEM_Persisted from term 1 to term 2		-0.018*	-0.021***	-0.005	-0.001

Variables	STEM Momen-tum Metric	State A, NSFY	State A, CC	State B, CC	State C, CC
		(0.010)	(0.005)	(0.004)	(0.005)
FEM_GPA of 3.0+ in Y1		-0.008**	-0.010***	-0.000	-0.009***
		(0.004)	(0.003)	(0.002)	(0.003)
FEM_Completed calculus credits in Y1	X	0.001	0.010***	-0.000	0.003
		(0.004)	(0.003)	(0.002)	(0.004)
FEM_Completed calculus fdn. credits in Y1	X	-0.003	0.008**	-0.001	-0.001
		(0.004)	(0.004)	(0.002)	(0.004)
FEM_Completed statistics credits in Y1		-0.003	-0.007*	-0.001	-0.016***
		(0.004)	(0.004)	(0.002)	(0.004)
FEM_Completed other CL math credits in Y1		-0.001	0.008**	-0.002	-0.028***
		(0.004)	(0.003)	(0.002)	(0.005)
FEM_Completed dev. ed. math credits in Y1		-0.008**	-0.011***	-0.004	0.003
		(0.004)	(0.003)	(0.003)	(0.003)
FEM_Math GPA of 3.0+ in Y1		0.000	-0.002	0.003	0.005
		(0.003)	(0.003)	(0.002)	(0.003)
FEM_Completed STE pathway credits in Y1	X	0.009***	0.009***	-0.000	0.002
		(0.003)	(0.003)	(0.002)	(0.004)
FEM_Completed STE fdn. credits in Y1	X	-0.008	-0.004	-0.005	-0.004
		(0.005)	(0.004)	(0.003)	(0.004)
FEM_Cd. other likely transferable STE credits in Y1		0.013	0.021	0.082	0.006*
		(0.019)	(0.013)	(3.374)	(0.003)
FEM_Cd. other likely CTE STE credits in Y1		0.022**	0.034***	0.008	0.007
		(0.010)	(0.007)	(0.007)	(0.011)
FEM_Completed any STE credits in Y1		0.009	-0.004	-0.078	0.013***
		(0.020)	(0.013)	(3.374)	(0.004)
FEM_STE GPA of 3.0+ in Y1		0.005	-0.002	-0.001	0.002
		(0.003)	(0.003)	(0.002)	(0.003)
Observations		50,230	84,881	50,594	94,875

Note. Standard errors in parentheses. All models include institution-by-cohort fixed effects. Variables with interaction terms are given the following prefixes: Interaction effects for women are labeled “FEM” and for historically underrepresented students of color—including Black, Hispanic, Native American, and Pacific Islander students—are labeled “HU.”

*** $p < .001$, ** $p < .01$, * $p < .05$