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Measuring STEM Momentum

Early Indicators of STEM Transfer Success for Community College Students

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Community colleges across the country are working to implement collegewide reforms— such as redesigns of new student onboarding or advising processes—to improve student success. Given their scale and scope, collegewide reforms are difficult to evaluate, and their effects on transfer or graduation rates may take years to observe. Yet 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 "early momentum" metrics, which research suggests are leading indicators of longer-term student outcomes (Jenkins & Bailey, 2017). Because they can be assessed quickly and consistently across years, early momentum metrics have been particularly useful for the hundreds of community colleges adopting guided pathways, a whole-institution reform model designed to improve how students enter and navigate through programs of study. Early momentum metrics have helped these colleges track improvements and provide formative assessments of student success reforms associated with the guided pathways framework.

However, early momentum metrics are program-agnostic. In one example of a widely used metric, first-year credit accumulation, a student may earn a substantial number of college credits in their first year, but those credits may or may not apply to a degree in their field of interest. This is a substantial limitation in the utility of such metrics, as program-specific coursetaking may be the strongest indicator of eventual transfer to and graduation from a four-year college (Denley, 2016; Jenkins & Cho, 2012, 2014). Moreover, institutional improvement aimed at greater student success requires the involvement of faculty and academic administrators within specific academic areas; these stakeholders often want to know whether or how reforms are benefitting students within their own programs (Bailey et al., 2015).

Overview

This brief summarizes findings from a study in which we examined postsecondary college transcript and degree records from hundreds of thousands of transfer-intending community college students in three states. Our aim was to explore and test metrics that could be useful in the formative assessment of efforts to improve STEM transfer outcomes. Our findings show that first-year completion of a calculus course and first-year completion of a (non-math) science, technology, or engineering (STE) course specified on statewide STEM transfer pathways are both reliable indicators of subsequent STEM transfer success across a wide range of state and institutional contexts. These two metrics are also robust predictors of success among subgroups of students by race/ethnicity and gender. In general, community colleges 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. The STEM momentum metrics identified in the study may therefore be useful for colleges seeking to strengthen STEM transfer outcomes and close equity gaps in STEM bachelor's degree attainment.

In this research brief, we summarize key takeaways from an accompanying technical paper (Fink et al., 2021) that seeks to identify and validate early program momentum metrics for community college students who aspire to transfer and complete a science, technology, engineering, or mathematics (STEM) bachelor's degree. We focus on STEM transfer as a case study for investigating program momentum metrics because community colleges represent an important potential pipeline for diverse talent into STEM fields. Historically, STEM professions have struggled even more than other fields to broaden participation to women, Black and Hispanic workers, and individuals from other minoritized groups (Riegle-Crumb et al., 2019). While community colleges serve a large proportion of persons from these groups, STEM transfer pathways are underperforming and inequitable; thus, community colleges are not living up to their potential to broaden access to STEM bachelor's degrees (Wang, 2020). For community colleges that are working to improve STEM transfer outcomes and close equity gaps, valid and reliable leading indicators of longer-term outcomes can provide timely and useful feedback on their efforts.

Our study used administrative records from nearly 270,000 transfer-intending students who began at 70 community colleges across three unidentified state systems. In summarizing key findings from this study, we focus in this brief on two primary 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 student groups that are historically underrepresented in STEM?

To answer these questions, we examined the association between different types of early community college STEM coursetaking and completion of a STEM bachelor's degree within six years of entering community college. Overall, we find that a simple set of four early STEM coursetaking metrics are more predictive of STEM bachelor's degree completion than general early momentum metrics (e.g., general first-year college credit accumulation, first-year math and English course completion). In particular, the most consistently useful indicator is first-year completion of a STEM course 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 but do not fulfill STEM bachelor's degree requirements (or may count only as electives).

The STEM momentum metrics identified in this research are reliable predictors across student race/ethnicity and gender. Furthermore, low and inequitable rates of STEM transfer and bachelor's degree completion can be traced back to low and inequitable rates of the STEM momentum metrics. The metrics identified through this research thus offer practitioners tools for the formative assessment of reforms aimed at strengthening STEM transfer pathways overall, as well as strengthening success among groups historically underrepresented in STEM fields.

Developing a Typology of Early STEM Coursetaking

The term "STEM" is deceptively simple, as it comprises numerous disciplines including biology, chemistry, physics, math, and others. Students beginning at community college who aspire to a career in STEM can pursue two very different types of programs: those designed for direct entry into the STEM workforce (e.g., applied associate degree programs) and those designed to prepare students for transfer into a STEM major at a four-year institution. As a result, most community colleges offer a broad variety of STEM courses, but it may not be clear which courses best foster transfer-intending students' STEM bachelor's degree aspirations and boost their momentum to transfer into STEM majors.

To explore which early STEM courses best predict subsequent STEM transfer success, we identified different types of early community college STEM coursework. Our STEM course taxonomy builds on prior work differentiating "likely terminal" (e.g., career and technical education courses) and "likely transferable" STEM coursework; we also differentiated math coursework from other, non-math STE coursework.[1] We organized courses according to whether they specifically appear on one of the statewide STEM transfer pathways ("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). We identified different math subject areas (e.g., calculus, precalculus, statistics) using course titles and standardized subject codes. To identify STE pathway and STE foundation courses, we linked information from statewide STEM transfer pathways and college catalogs to our transcript-level student administrative records in each state. The detailed STEM course taxonomy, with definitions and examples, is presented in Table 1.

Statewide STEM Transfer Pathways

In each of the three states under study, community college and university stakeholders have established STEM transfer pathways designed to facilitate community college STEM transfer students with entry into specific STEM majors with junior standing at one of the state's public (and in some cases private) four-year institutions. 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. These agreements also provide guidelines for other general education or elective courses that students should complete during their first two years at community college to enter as a junior in their chosen major at a public university. In all three states, transfer pathways were initially developed and are periodically updated by discipline-specific faculty work groups that include representatives from both two- and four-year institutions, convened by state agencies or other statewide organizations. In all three states, the statewide STEM transfer pathways are used as advising guides for transfer-intending community college students; they provide clear road maps to guaranteed entry into STEM majors after transferring to one of the state's public universities.

Table 1.
Community College STEM Course Typology

Math course type	Definition	Examples	
Calculus	Any calculus course	Calculus I/II	Key STEM momentum metric course
Calculus foundation	Any college-level precalculus, trigonometry, geometry, or algebra course	Precalculus Trigonometry/Geometry College Algebra	Prerequisite course
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 any STE course that applies to a university STEM major program and enables students to enter a university "major-ready" in STEM	Chemistry I/II Biology I/II Physics	Key STEM momentum metric course
STE foundation	College-specific prerequisite course for STE pathway courses	Intro to Chemistry Intro to Biology Intro to Physics	Prerequisite course
Other STE, likely transferable	Likely transferable course based on two-digit CIP codes from Wang (2016); not included in pathway or foundation categories	Introduction 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	Broadly defined STE course that includes any of the courses above and all courses with STE CIP codes based on Wang's (2016) classification but excluding math coursework	All of the above	

Findings

1. Early STEM momentum metrics predict longer-term STEM transfer success.

Across the three states in our study, we find that completion of a calculus or STE pathway course in students' first year at community college is the strongest predictor of STEM bachelor's completion. For instance, in State A, 24% of community college students who completed a STE pathway course during their first year went on to earn a STEM bachelor's degree within six years of entry (compared to 3% overall). In State C, 23% of students who completed a calculus course in their first year earned a STEM bachelor's degree within six years of entry (compared to 4% overall). Early completion of a calculus or STE foundation course also has a positive relationship with STEM bachelor's degree completion, though it is a weaker predictor than calculus or STE pathway course completion. In general, early completion of calculus or STE pathway coursework is substantially more predictive than program-agnostic early momentum metrics (such as first-year completion of 24 college-level credits or completion of college English).

Table 2 presents descriptive results on STEM bachelor's degree completion among different samples of students (e.g., all transfer-intending community college entrants, those who completed STE pathway courses).[2] In State A, for example, only 3% of transfer-intending community college entrants eventually earned a STEM bachelor's degree. Among transfer-intending students who completed 24 or more credits in their first year, chances of earning a STEM bachelor's degree tripled (to 9%); but among those who completed a calculus course in their first year, chances of earning a bachelor's degree increased nearly ninefold (to 26%).[3]

Table 2.

Six-Year STEM Bachelor's Degree Completion Rates for Transfer-Intending Community College Students by Momentum Indicator

		State A (*N* = 92,679)	State B (*N* = 50,890)	State C (*N* = 124,628)	State A	State B	State C
All transfer-intending community college entrants		**3%**	**1%**	**4%**	**Factor increase above baseline**		
General academic momentum indicator	Completed 24+ credits in year 1	9%	3%	6%	3.0	3.0	1.5
	Completed college English credits in year 1	4%	1%	5%	1.3	1.0	1.3
	3.0 GPA in year 1	6%	2%	7%	2.0	2.0	1.8
STEM momentum indicator	Completed calculus foundation credits in year 1	16%	4%	11%	5.3	4.0	2.8
	Completed calculus credits in year 1	26%	14%	23%	8.7	14.0	5.8
	Completed STE foundation credits in year 1	7%	3%	9%	2.3	3.0	2.3
	Completed STE pathway credits in year 1	24%	6%	25%	8.0	6.0	6.3

2. STEM momentum metrics are reliable indicators for women and underrepresented students of color.

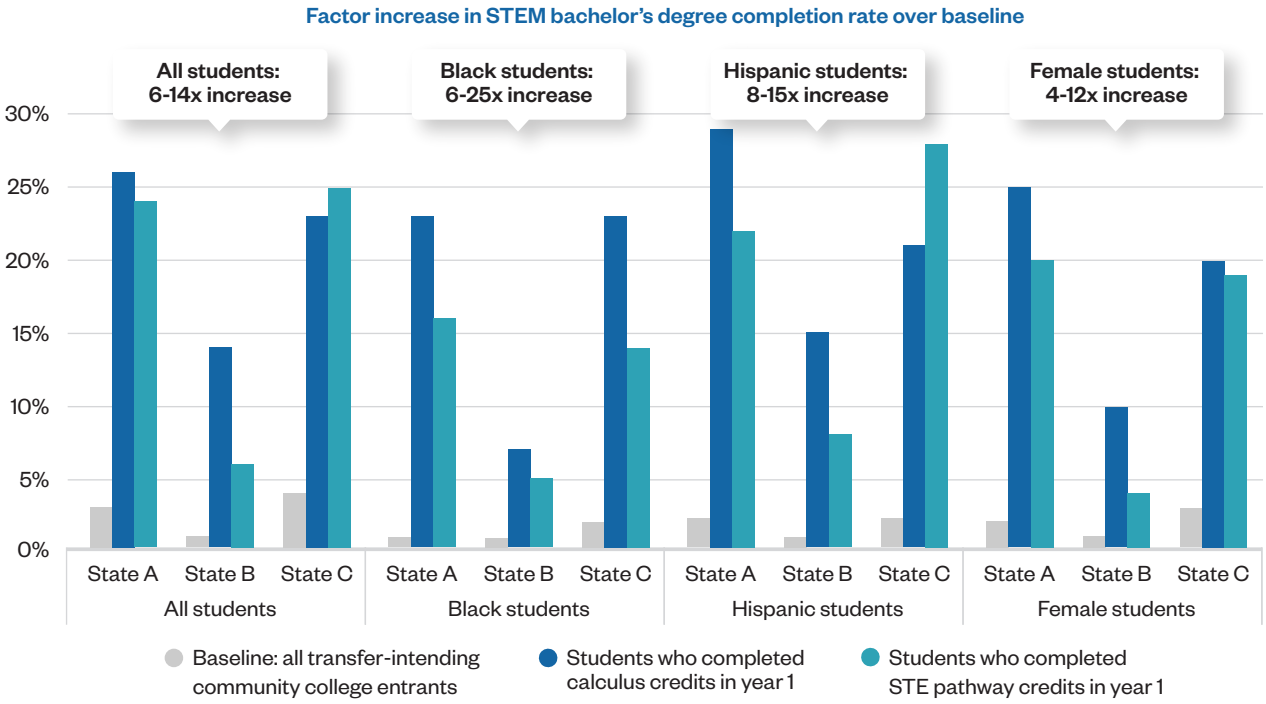
To answer our second research question, we further examined whether the four STEM momentum metrics could reliably predict STEM bachelor's degree attainment for women and racially minoritized

students of color—two groups that have been historically underrepresented in STEM fields.[4] These analyses are important as they can help to determine whether college leaders should first work to close equity gaps in STEM momentum metrics in order to eventually close gaps in longer-term outcomes. For this to be a fruitful strategy, the predictive power of STEM momentum metrics must be as strong or stronger predictors for women and students of color as they are for men and nonminoritized students. Overall, we find that the predictive strength of early completion of calculus or STE pathway coursework—the strongest predictors of STEM bachelor's completion—are consistent across all student groups.

To illustrate the relationship between early completion of calculus or STE pathway coursework and subsequent STEM transfer success across student groups, Figure 1 shows the increase in STEM bachelor's degree completion rates for women, Black, and Hispanic students who completed these key STEM courses in their first year, compared to all transfer-intending community college students.

Figure 1.

Six-Year STEM Bachelor's Degree Completion Rates for Transfer-Intending Community College Students by First-Year STEM Coursetaking and Student Demographics



3. Few students gain early STEM momentum, and equity gaps present early on.

Despite the strong association between early calculus or STE pathway course completion and STEM bachelor's degree completion, very few community college students complete these courses in their first year. Instead, colleges typically place students into prerequisite foundation STEM courses or other STEM courses that may not transfer to a four-year college or may transfer but not fulfill STEM bachelor's degree requirements. Moreover, we find clear disparities by race/ethnicity and gender in calculus and STEM pathway coursetaking during students' first year at community college (see Table 3). In State B, for example, 6% of community college students completed a STE pathway course in their first year of enrollment; notably, only 2% of Black students did so.

Table 3.

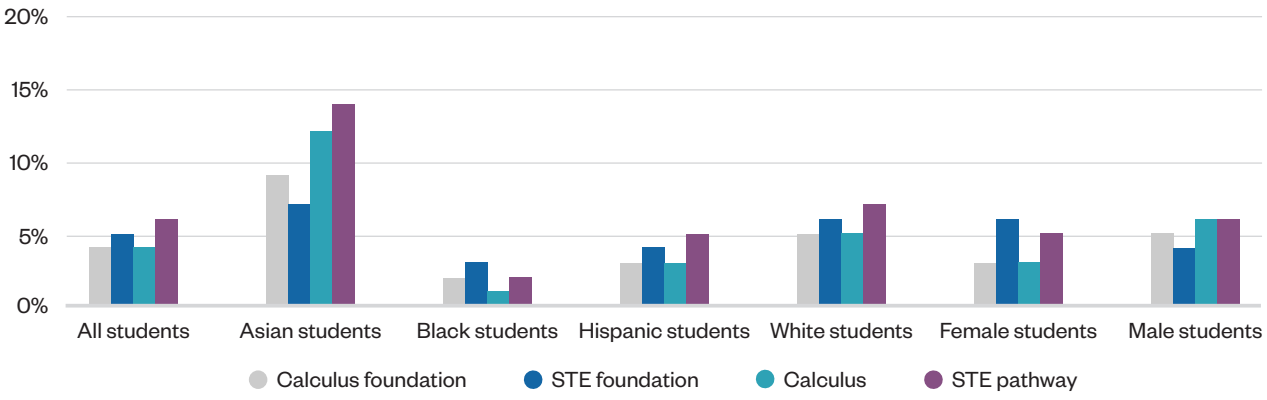
First-Year STEM Coursetaking Among Transfer-Intending Community College Students by Gender and Race/Ethnicity

	Completed calculus credits in year 1			Completed STE pathway credits in year 1		
	State B (*N* = 50,890)	State C (*N* = 124,628)	State C (*N* = 124,628)	State A (*N* = 92,679)	State B (*N* = 50,890)	State C (*N* = 124,628)
All Students	6%	4%	4%	4%	1%	6%
Gender						
Female	5%	3%	3%	3%	1%	6%
Male	7%	4%	4%	6%	2%	7%
Race/ethnicity						
Asian	9%	7%	7%	12%	6%	16%
Black	2%	2%	2%	1%	1%	3%
Hispanic	6%	2%	2%	3%	3%	2%
Native/American Indian	7%	2%	2%	2%	1%	2%
Pacific Islander	7%	2%	2%	3%	<1%	2%
White	7%	3%	3%	5%	2%	4%
Other/unknown	3%	3%	3%	4%	1%	3%

As another example, Figure 2 shows results from State A in terms of first-year STEM course completion by race/ethnicity and gender, illustrating how rates of early STEM momentum are both low and inequitable.

Figure 2.

State A, First-Year STEM Coursetaking Among Transfer-Intending Community College Students by Gender and Race/Ethnicity



Practical Considerations for Improving STEM Transfer Success

Community colleges seeking to create more equitable access to their college and improve outcomes for their students should consider how ongoing student success reforms and related statewide transfer pathway development can better support success for all students. More specifically, they should examine the systemic challenges that might be contributing to low and inequitable rates of early completion of key STEM courses. While the positive relationship between key STEM course completion in the first year and longer-term STEM bachelor's degree completion is fairly consistent for students across gender and racial/ethnic groups, much work remains to ensure that all students have access to and adequate support for completing these courses. In the following subsections, we provide practical approaches for state systems and individual community colleges looking to improve the STEM transfer success of their students, including: (1) clearly

identifying STE pathway courses and communicating this information to students, (2) identifying and supporting STEM transfer-intending students early in their college experience, and (3) rethinking STE foundation courses.

Identifying STE Pathway Courses and Communicating with Students

We found that completion of a non-math STE pathway course like Chemistry I/II or Biology I/II was as strong a predictor of STEM transfer success as completion of Calculus. Thus, in addition to college efforts to accelerate math completion, similar attention should be directed toward helping more STEM-aspiring transfer students complete non-math STE pathway courses. To do so, colleges and students need to know which courses are STE pathway courses and will fulfill STEM baccalaureate major requirements. Like in the three states in this study, this information may be available through statewide agreements; as many as 39 states have policies requiring the statewide mapping of academic transfer pathways (Zaragoza, 2021). Yet it remains unclear how many of these states have *major-specific* agreements in place. Some states have general education transfer agreements, others have course-by-course equivalencies (which do not ensure applicability to particular majors), and still others have no statewide agreements. Furthermore, the process for developing such major-specific pathways (e.g., whether disciplinary faculty are engaged, how often pathways are updated), as well as their implementation and utilization among colleges and students, can vary considerably (Schudde et al., 2020).

Given that community college students often receive little guidance on what courses will transfer to their program of interest at a four-year college, statewide major-specific agreements better equip advisors and students with information on which pre-major courses will not only transfer but also apply to baccalaureate degree programs—information that otherwise can be difficult to ascertain. Statewide or regional groups, such as state higher education agencies or other governing boards, can play a key role in facilitating multi-institutional coordination on major-specific transfer pathways. When done well, program-level coordination between community colleges and universities can bring more clarity on the general education and pre-major courses that will apply to students' intended bachelor's degree programs. And while existing bilateral transfer partnerships may be strongest between staff in admissions and advising, partnerships at the program-level among faculty in similar disciplines can create benefits for transfer students in other areas even beyond course articulation, such as pedagogical alignment and access to enriching cocurricular learning opportunities (Wyner et al., 2016).

Identifying and Supporting STEM Transfer-Intending Students

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. Results from this study indicate that the most common type of early STEM coursetaking is not in courses specified on statewide STEM transfer pathways or even in prerequisite foundation courses, but rather in the category we refer to as "likely transferrable" STEM courses (i.e., not necessarily applicable to STEM majors, and not the courses that we find to be most predictive of successful STEM transfer and bachelor's degree completion). This raises questions about how many of the students taking these likely transferable courses might aspire to transfer into STEM fields and whether these courses will actually apply to their eventual bachelor's degree program.

A supplementary analysis of the availability of STE foundation and pathway courses in our sample finds that most of the courses offered by community colleges 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 in fall 2018, among community college biology courses, only 24% were STE pathway courses, and 12% were STE foundation courses. A similar pattern emerged in State C; in fall 2019, for example, calculus courses

comprised 16% of college-level math courses offered by community colleges, and calculus foundation courses accounted for an additional 21%. These supplementary analyses raise further questions, such as: What are the other types of STEM courses students are taking, and do these courses count toward the degrees these students aspire to earn?

Community colleges typically do not keep detailed records of students' intended transfer programs, which makes it difficult to provide proactive advising and support that will ensure that students enter a baccalaureate major with junior standing and with credits that will actually apply to their degree program (Fink & Jenkins, 2020). 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 them to better identify, orient, and advise students who aspire to transfer into STEM. By identifying in students' first year what broad fields of study they intend to pursue, colleges are better equipped to connect them to courses, faculty mentors, and experiences that will help them build early program momentum (Jenkins et al., 2020). Guided pathways reforms, which help students explore and navigate through a field of study, can work in tandem with statewide efforts to create more structured transfer pathways, as these efforts provide clearer information to community college advisors and students about which courses will apply to students' bachelor's degree requirements.

Rethinking Foundation for STE Pathway Courses

The results of our study suggest that college leaders can work to close equity gaps and improve STEM transfer success by helping more students, particularly those from historically underrepresented groups, to enroll and succeed in calculus and STE pathway courses, which are especially strong and reliable early indicators of STEM bachelor's completion. The prerequisite, or foundation, courses to these statewide transfer pathway courses, though still somewhat predictive, are notably weaker predictors of STEM transfer bachelor's degree completion.

Foundational STEM coursework often consists of courses that could be completed at the high school level, such as algebra, precalculus, 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. Colleges receive a steady stream of STEM-intending students who have either not recently completed high school or who have not completed such foundational coursework in high school. As a result, colleges typically place these students into a series of preparatory, or foundational, courses (in both math and non-math subjects). For example, in two of the states under study, students seeking to enroll in transfer-level general chemistry coursework may first be required to complete preparatory coursework in three different subject areas: developmental math, developmental English, and introductory chemistry (through an introduction to chemistry or general chemistry preparatory course).

Although foundational non-math STE courses (e.g., Introduction to Chemistry) do earn students college-level credit, in many ways the foundational STE 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 math and English 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, community college STE departments, such as physics, chemistry, or biology, may find it instructive to learn about mathematics reforms that accelerate the academic momentum of students who arrive at college underprepared in math subjects. 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 (Brathwaite et al., 2020; Purnell & Burdman, 2021). 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; Wang et al., 2021; Zachry Rutschow et al., 2019).

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).

Conclusion

The STEM momentum metrics identified through this study are more actionable than longer-term outcomes, such as STEM transfer or bachelor's degree completion rates in a three- or six-year time span, and they are closer to practice than existing, program-agnostic early momentum metrics. They may therefore be valuable in the formative evaluation of efforts by program faculty and college leaders to close equity gaps in STEM fields and improve STEM transfer outcomes. By tracking disaggregated rates of student completion of key STEM transfer courses and their prerequisites, program and college leaders can better assess the effects of efforts to improve student outcomes and make corrections based on what is and is not working.

While we focused on reporting statewide findings in this research, we observed substantial differences among colleges within each state in terms of their effectiveness in helping more students gain early STEM transfer momentum by completing key calculus and STE pathway coursework. 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 than others. Future research should seek to learn from colleges that are doing better in this regard, particularly from colleges that are more effective at helping women and underrepresented students of color gain early STEM momentum.

Endnotes

1. Wang (2016) used two-digit CIP codes to identify STEM transfer courses and to classify those that were "likely transferable" to a four-year college. We extend Wang's concept of "likely transferable" STEM courses in two ways: first, by identifying courses that are specified on statewide STEM transfer pathways as satisfying STEM baccalaureate degree requirements and, second, by separating math from other STE so as not to conflate math momentum with non-math STE momentum.
2. These findings are corroborated by more detailed analyses using logistic regression controlling for student and institutional characteristics presented in our working paper (Fink et al., 2021). 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.
3. One limitation of our study is a lack of high-quality information regarding community college student majors, as transfer-intending community college students are typically enrolled in generic

majors such as "general transfer." In the working paper (Fink et al., 2021), we further examined the relationship between the STEM momentum metrics and STEM transfer outcomes for various subgroups of potentially STEM-intending transfer students, and the results supported our findings more generally.

4. We included Black, Hispanic, Native American, and Pacific Islander students in the "racially minoritized students of color" group.

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