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The Relationship Between Course-Taking Patterns in Undergraduate Biology and Community College Transfer-Success

By

Linda Fergusson-Kolmes

A dissertation submitted in partial fulfillment
of the requirements for the degree of

Doctor of Education
in
Leading and Learning

University of Portland
School of Education

2021

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The Relationship Between Course-Taking Patterns in Undergraduate Biology and Community College Transfer-Success

by

Linda Fergusson-Kolmes

This dissertation is completed as a partial requirement for the Doctor of Education (EdD) degree at the University of Portland in Portland, Oregon.

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Abstract

The purpose of this non-experimental, quantitative study was to investigate the relationship of course-taking patterns of community college students enrolled in a major's biology sequence to successful transfer into a biology or biology-related degree track at four-year institutions. The research was guided by the seminal work of Adelman (1999, 2006) on course-taking as it relates to academic momentum and the STEM transfer model developed by Wang (2016b). The relationship of course-taking behavior to transfer outcomes for a population of students in a biology transfer sequence at a large, community college in the Western U.S. was addressed using anonymized student transcript data provided by the institution and post-community college enrollment records from the National Student Clearinghouse database.

Multinomial logistic regression was used to investigate the predictive value of leading indicators of academic momentum for the study population, previously identified for community college students in general (Adelman, 1999, 2005; Belfield et al., 2019; Jenkins & Bailey, 2017). Findings indicated that only first term grade point average (GPA) was a significant predictor of transfer for the overall model (χ^2 = 9.20(3), p = .03).

Further examination of course-taking behavior found that students had a broad range of college-level coursework in biology, chemistry, physics, and math prior to enrolling in the first class in the major's sequence. Prior coursework was significantly related to outcomes. Disaggregation of the course-taking behavior revealed differences based on gender, age, race, and ethnicity. There were significant differences in biology, chemistry, and math coursework completed prior to enrolling in the first course in major's biology based on age but not gender, race, or ethnicity. Few differences in outcomes were found based on gender or age category. However, enrollment intensity varied significantly for students during the term they first attempted major's biology based on both age and gender but not race or ethnicity.

The value of course-taking behaviors, outcomes in major's biology, and enrollment intensity as predictors for transfer outcomes was explored using a logistic regression model. Results suggest that outcomes in the gateway major's biology course may be a useful leading indicator for academic momentum for students in a major's biology sequence. The overall picture of completion and retention suggest that the first course in the major's biology sequence is a not just a gateway but a 'gatekeeper'. Recommendations for improving outcomes in major's biology based on this study include promoting early student access to discipline specific advising and tutoring. Additionally, given the heterogeneity of college-level STEM preparation for students attempting the major's biology sequence for the first time, teaching strategies that facilitate equitable learning environments are an important component of supporting student success.
Keywords: academic momentum, leading indicators, biology, community college

Dedication

To community college students everywhere believing in the promise of education.

Acknowledgements

It may take a village to raise a child, but it takes an even broader community to support that child into adulthood on their journey of life long learning. Thank you to all who have accompanied me on this journey. Some of you have been walking with me for a long time and some for a few critical steps.

Thank you and love to my family: Steve, Sara, Eli, Thijs, Mom and Dad. You were the providers of inspiration, practical support, and an abundance of commas.

Thank you to my chair, Dr. Rebecca Smith, for your optimism, guidance, and also a liberal sprinkling of commas. Additional thanks to Dr. Arwood for inspiring the decision to start the trip. Deep gratitude to the members of my committee, Dr. Ralston and Dr. Weitzel. Thank you also to Dr. Hetherington, Dr. Carroll, Dr. Waggoner, for building the road and providing a map. Congratulations to the rest of the doctoral cohort. You have been wonderful traveling companions.

This would not have been possible without the support of the Office of Institutional Effectiveness, the Dean of Instruction and my COVID kayaking buddy.

Finally, thank you to the Creator of miracles both large and small. I never walked alone.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Economic projections suggest that the need for qualified individuals trained in science, technology, engineering, and mathematics (STEM) will grow almost 9% between 2014 and 2024 (Noonan, 2017). The National Science Foundation (NSF) has expressed concern that enrollment in STEM fields at the undergraduate level in the United States will not be able to meet the projected workforce demand (NSF, 2017). Some authors challenge this projection and suggest that the educational system is producing the number of required STEM graduates needed (Salzman & Benderly, 2019). These authors suggest that the focus should be on increasing the engagement in STEM of a broader range of students given that representation of women and historically underserved racial and ethnic groups in STEM occupations currently does not match the demographic profile of the American population (National Science Board [NSB], 2019); Salzman & Benderly, 2019). Regardless of the fluctuating workforce projections, the discrepancy between students who indicate an interest in a STEM field and those who persist warrants further examination at the level of undergraduate education (Riegle-Crumb et al., 2019).

Diversifying STEM Engagement in Undergraduate Education

Diversifying the engagement in STEM of a broader range of students at the undergraduate level is an important goal (NSB, 2019; NSF, 2017). While enrollment in institutions of higher education by some historically underserved students is increasing, the completion of STEM degrees is not increasing similarly in all populations (Musu-Gillette et al., 2017; NSB, 2019; NSF 2017; Valantine & Collins, 2015). The reasons for this discrepancy are complex, but some explanations are connected to the experience students have at their undergraduate institutions. Riegle-Crumb et al. (2019) found little difference between the percentages of African-American, Hispanic, and White students who chose a STEM major upon college entry. These researchers and others found that students from historically underserved ethnic and racial groups who initially enrolled in a STEM major were more likely to leave or switch majors than White students (Ferrare & Lee, 2014; Riegle-Crumb et al., 2019; Seymour & Hewitt, 1997). Serious efforts are being made nationally to recruit, retain, and encourage completion in STEM majors for all students but particularly for historically underserved students. These efforts include the National Science Foundation (NSF) Improving Undergraduate STEM (IUSE) grant program, the Louis Stokes Alliance for Minority Participation, the National Institutes of Health's Building Infrastructure Leading to Diversity (BUILD), and calls for reform of teaching in undergraduate STEM (Brewer & Smith, 2011; Laursen, 2019; National Academies of Sciences [NAS], 2019). Understanding the role of early course-taking patterns for the retention of students who are interested in STEM may inform efforts to support historically underserved students.

Importance of Community College Transfer Function

Community colleges may be an underdeveloped resource for meeting the need for a more diverse STEM-related workforce given the importance of the transfer function and their student demographics (NAS, 2019; Wang, 2015). Community colleges serve many functions that are important to the American educational landscape. Community colleges enrolled close to 5.4 million first-time students in fall

2019 (National Student Clearinghouse Research Center [NSCRC], 2019). This number represented approximately one-third of the undergraduates in the U.S. in 2019 (NSCRC, 2019). For this large number of students, community colleges have different functions, including adult education, workforce training, and earning transfer credits towards a baccalaureate degree.

The community college transfer function is highlighted by the large number of students who access resources at a community college on the path to a baccalaureate degree (NSCR, 2019; Shapiro, Dundar, et al., 2019; Shapiro, Ryu, et al., 2019). Federal data indicate that 53% of students who completed a baccalaureate degree at a four-year school between 2010 and 2017 had previously attended a community college. The STEM specific transfer function suggests additional potential for engaging a broader range of students in STEM, given that 47% of students earning a degree in science or engineering had attended a community college (NSB, 2019).

One of the original purposes of community colleges was to provide greater access to higher education by providing an affordable transfer path to four-year institutions for students who might not otherwise be able to attain a baccalaureate degree (President's Commission on Higher Education, 1947; Vaughan, 1982). The combination of affordability and open access have resulted in community colleges serving a high proportion of students who are first- generation, post-traditional (older than the traditional 18 to 23 year old student), have disabilities, come from lower socioeconomic groups, or are members of other historically underserved populations. Therefore, the population is substantially different than many four-year institutions. For instance, the average age of a full-time community college student at the beginning of the school year in 2019 was 1.3 years older than a traditional full-time student at a four-year institution who enters college directly from high school. Additionally, community college students who were financially dependent on their parents were more likely to come from the lowest family income quartile than their counterparts at four-year institutions (Ma & Baum, 2016). Community colleges are also more likely to be the school of choice for Latinx, Native Americans, Pacific Islanders, students with disabilities, and first-generation students (Cataldi et al., 2018; NAS, 2019; National Science Foundation [NSF], 2017). Understanding how this population of students accesses the transfer function opportunities available at a community college is important for increasing the engagement in STEM.

Community College Transfer Function Challenges

Community colleges provide an opportunity to diversify engagement in STEM given their population demographics and the importance of the transfer function. This potential of community colleges to play an essential role in increasing the participation of historically underserved students in STEM is challenged by the completion data that suggest that rather than democratizing, community colleges serve to stratify educational outcomes further (Dowd, 2007; Schudde & Grodsky, 2018). For example, completion rates for community college students are low and disproportionately low for historically underserved students, indicating the presence of an opportunity gap (Juszkiewicz, 2019; Shapiro et al., 2017b). Estimates for completion vary widely depending on how they are measured and whether three, six, or eight-year time frames are used. For a cohort of students who began community college in 2012, depending on the metric, completion rates range from 27% to 61% (Juszkiewicz, 2019). Using comparable measures and an eight-year time frame, students who began college in 2010 at a public four-year institution had higher completion rates compared to a similar cohort of community college students; completion rates were close to 69% for students at four-year institutions compared to just over 45% for students at two-year public institutions (Shapiro, Ryu, et al., 2019). Improving completion has become part of the national agenda for community colleges as they seek to fulfill their promise to democratize education (Bailey et al., 2015).

As reform initiatives get underway, the debate continues about whether community colleges are serving their transfer function well. Some studies (Long & Kurlaender, 2009; Reynolds, 2012; Rouse, 1995) have found a negative association between beginning at a community college and eventually attaining a baccalaureate degree, proposing that attendance at a community college represents the diversion of qualified students from their educational goals. Alternatively, other research has found no negative association when other demographic factors are controlled for, suggesting that community colleges represent a viable option (Monaghan & Attewell, 2015). For example, in a study using longitudinal data from the National Center for Education Statistics (NCES), Melguizo et al. (2011) found that students who began at a four-year institution and students who transferred in from a community college were significantly different in their level of high school preparation and in other socio-demographic characteristics. Given the initial disparities in the two groups, when the researchers used propensity matching to control for these factors, they found no significant difference in the degree outcomes between the transfer students from community colleges and the students who began at four-year institutions. Furthermore, some authors suggest that because the characteristics of the student population and resulting enrollment patterns are heterogeneous, characterizing the effect of community college attendance on the probability of a student attaining a baccalaureate degree must be done considering the context of the student, as well as institutional characteristics such as size or geographical location (Brand et al., 2012; Umbach et al., 2019). This research suggests that maximizing the potential of community colleges to increase diversity in STEM participation must be done with an understanding of the role of the community college and the identity of the student, specifically in a STEM context.

STEM Engagement at the Community College

Work directed at understanding the community college STEM context has resulted in the development of a STEM transfer model (Chan & Wang, 2018; Wang, 2015, 2016a, 2016b; Wang et al., 2019). Wang's STEM transfer model (Wang, 2015, 2016b) builds on the concept of academic momentum as a leading indicator for student success (Adelman, 1999, 2006; Attewell et al., 2012) and uses the definition of momentum from physics – a combination of mass and velocity – to conceptualize the relationships between factors important for community college students to be successful in STEM. Wang (2015) theorizes that completion in STEM is influenced by the early academic momentum that students obtain based on the number of credits (mass) and the quality of attainment (velocity). In a study using national data for students enrolled in STEM classes at a post-secondary institution in the 2003-04 academic year, the degree outcomes of matched groups of students beginning at a community college and at a four-year institution were compared (Wang, 2015).

Starting at a community college had a significantly negative effect (*p* < .001) on completing a baccalaureate degree (Wang, 2015). This finding is balanced by the evidence that elements associated with gaining academic momentum in a STEM degree, such as the number of first term STEM credits, the grades achieved in STEM courses, and summer enrollment, had a relatively greater positive impact on the outcomes of community college students than for their counterparts at public four-year institutions. This research suggests that while the community college population may be at a disadvantage, there is the opportunity to accelerate progress if the complex elements related to momentum are characterized well enough to understand where interventions would be effective.

The current picture of engagement in different STEM disciplines underscores the need to consider disciplines separately. Participation in different STEM fields is not homogenous (NSB, 2019). In 2017, the overall number of STEM baccalaureate degrees awarded in the U.S. increased and almost reached gender parity, with slightly more than half of the degrees earned by women (NSB, 2019). The picture is very different when broken down by discipline, with over 60% of the baccalaureate degrees in biological sciences earned by women at one end of the spectrum, and less than 20% of the computer science degrees earned by women at the other end. When the numbers are disaggregated by race and ethnicity, differences are also seen in the number of baccalaureate degrees earned in different STEM disciplines (NSB, 2019). This finding may reflect differences in the disciplinary cultures within STEM (Reinholz et al., 2019). The difference in the responses to the national call to reform teaching and learning in undergraduate STEM education may also reflect disciplinary culture

(Laursen, 2019; Malcom & Feder, 2016). If the student populations are different and the efforts to reform teaching vary between STEM disciplines, then to understand STEM momentum at a community college there is a need to examine student pathways in a discipline specific way.

Community College Completion Reform Initiatives

Numerous reform initiatives have influenced the focus of community colleges student transfer pathways (Bailey et al., 2015). Community colleges have been increasing efforts to improve student success since the Student Right-to-Know and Campus Security Act was passed in 1990 (Bailey, et al., 2015; Dougherty et al., 2017). These laws required all institutions of higher education that receive Title IV funding, to report retention and graduation rates (S.580, 1990). Many colleges across the nation are shifting from a focus on providing access to education to student-focused completion rates. In some states, the shift in focus has been accelerated by adoption of funding models incorporating completion rates (for a review of reform initiatives see Offenstein & Shulock, 2010). The adoption of a guided pathways model has many colleges restructuring student orientation, instruction, and advising (Bailey et al., 2015). While the model is implemented differently on each campus, one of the more common outcomes is the development of clearly sequenced course maps designed to align with student goals (Bailey et al., 2015; Dougherty et al., 2017; Jenkins et al., 2018). Colleges that are in the process of switching to a guided pathways model are asking faculty members to develop the appropriate maps for their disciplines (Bailey et al., 2015). For STEM disciplines, these course maps are informed by the transfer requirements in each major at four-year schools and existing articulation agreements.

These maps provide sequences based on prerequisites, but some of the sequencings in the course maps are arbitrary (Bailey et al., 2015). Students can progress through the transfer map differently based on the course sequence they choose. In addition, students also have different entry points into a sequence based on their academic preparation for courses like English or math (Bahr et al., 2017). An understanding of the impact of course sequences and variable entry points on student success would be useful for implementing appropriate curricula and for assessing the impact of student completion reform initiatives like guided pathways. Assessing appropriate curricula in the transfer pathway program map would be informed by an understanding of the relationship between the course-taking and achievement in upper-division courses at the primary receiving institution.

Research Gap

The limited information about the effect of course sequence and course-taking behavior on early academic momentum in specific STEM disciplines at community colleges suggests that there are differences associated with socio-demographic factors. Previous research (e.g., Hagedorn & DuBray, 2010) has found that there are differences in the progression of community college students through courses for a STEM major based on gender, race and ethnicity, and the degree of remediation required to reach college-level math. For instance, Wang (2016a) studied the course-taking in beginning community college students and found differences in the timing of math enrollment for students who transferred successfully in STEM compared to those that did not. Wang (2016a) also found differences in the number of math credits accumulated by students successfully transferring in STEM based on gender and age.

Additionally, Bahr et al. (2017) mapped the course-taking patterns for community college students in math, chemistry, and physics tracks and also found differences related to student demographics and STEM discipline. The relationship between student demographic and STEM discipline was not always consistent, as evidenced by Hagedorn and Dubray (2010), who found significant differences in the grades based on race and ethnicity for introductory biology and physics classes but not for introductory chemistry. Another study (Cohen & Kelly, 2019a) examined the relationship between performance and persistence in an introductory STEM gateway course and found differences in the predictive value depending on the STEM discipline, including opposite outcomes for students taking introductory chemistry compared to biology. These results suggest that more work needs to be done to examine the interaction between course-taking behavior, student demographics, and specific STEM disciplines to inform the curricula associated with guided pathways reform initiatives at community colleges. If community colleges are to fulfill their transfer function and serve as an effective route for students interested in STEM, the relationship between course-taking patterns and historically underserved populations needs to be better understood to close the opportunity gap that currently exists.

These findings, in conjunction with biological science being one of the top five majors for undergraduates and one of the growing disciplines in STEM, make the course-taking behavior in biology important to describe (NSB, 2019; NSCRC, 2019; Shapiro et al., 2019). This discipline also represents an opportunity to diversify engagement in STEM, since student intent to major in Biological or Agricultural Science is higher for a more diverse demographic of students compared to intent to major in engineering, mathematics, and computer sciences or physical sciences (Eagan et al., 2017).

Purpose Statement

The purpose of this quantitative study is to investigate the relationship of course-taking patterns of community college students enrolled in biology courses to successful transfer into a biology or biology-related degree track at four-year institutions, by means of descriptive statistics to map student transcript information, and multinomial logistic regression. For the purposes of this study, transfer is defined as enrolling in a four-year institution after taking classes at a community college. The findings inform curriculum development, biology transfer maps in a guided pathways reform initiative, and support services related to advising community college students in science, technology, engineering, and math (STEM). The specific research questions investigated include:

Research Question One

To what extent do the leading indicators that predict successful transfer to a four-year institution identified for community college students in general, also predict transfer outcomes for students in a biology transfer sequence at a large western community college?

Research Question Two

What was the pattern of course-taking behavior of students in a biology-degree transfer sequence at a large western community college?

Research Question Three

What was the pattern of course-taking behavior in a biology-degree transfer sequence for students, disaggregated by gender, age, race, and ethnicity, at a large western community college?

Research Question Four

What was the relationship between the course-taking behavior in a biology-related degree sequence and predicting transfer to a four-year institution into a biology or biology-related degree track?

Significance

Community colleges are an important element in the pathway to diversifying the STEM workforce (Bahr et al., 2017; Wang, 2015). Given that approximately one-third of the undergraduate in the U.S. in the fall of 2019 attended community college (NSRC, 2019) and that those students represented a diverse socio-demographics, the transfer function for community colleges represents an important stepping stone in the pathway to diversifying the STEM workforce. The low rates of successful transfer in STEM disciplines suggest that there is opportunity to improve the pathway (Bahr et al., 2013, 2017; Bailey et al., 2015; Wang, 2015). Reform initiatives are occurring in many community colleges to diversify participation in science, technology, engineering, and math (STEM) fields, specifically to increase completion and narrow opportunity gaps for historically underserved student population (Belfield et al., 2019; Malcom & Feder, 2016). Leading indicators that predict student success are useful for estimating the effectiveness of such reform initiatives. Previous research has identified leading indicators that help predict success in community college students, both for the general student body and for students in STEM. Initial work in STEM suggests that a more detailed understanding of leading indicators related to course-taking patterns that contribute to academic momentum specific to each STEM discipline is needed. Understanding course-taking patterns, how they relate to success, and differences based on gender, age, race and ethnicity, may help colleges to adjust during periods of institutional reform. Additionally, information on how students gain academic momentum for successful transfer or completion may help institutions deploy resources more effectively to improve transfer success, decrease opportunity gaps and ultimately help diversify participation in STEM fields (Belfield et al., 2019; Jenkins & Bailey, 2017; Malcom & Feder, 2016).

The results of this study inform policies and practices related to the implementation of the guided pathways reform initiative currently underway at the community college study site (Bailey et al., 2015). Part of the reform initiative has included providing students with program specific course maps to follow to achieve their goals. Information learned about the course-taking patterns of students interested in biology could inform the current sequence of proposed courses for students identifying transfer in biology or a biology-related degree as their goal. Information about leading indicators of academic momentum related to success in a biology transfer track could also inform institutional decisions about how to use resources to best support students (Offenstein & Shulock, 2010). The advising redesign process that is underway as part of the guided pathways reform initiative would benefit from any additional insight gained into optimal course-taking patterns for equitable transfer success (Bailey et al., 2015).

The findings of this study will benefit community college students by providing insight into the major transfer maps. The goal for developing major transfer maps was to provide pathways for students from all 17 of Oregon’s community colleges the ability to transfer without credit loss to any of the state public universities after the passage of OR-HB 2998 (2017). One of the first pathways to be outlined in the state was the major transfer map for biology (Higher Education Coordinating Commission [HECC], 2020). As the transfer map is implemented, information from this study on course-taking behavior in biology can inform advising for students trying to follow the map.

Finally, information on the relationship of course-taking behavior of community college students and transfer success in the STEM discipline of biology adds to the emerging literature on this topic. Initial work suggests that there are differences between STEM disciplines in the details of course-taking patterns related the successful transfer and completion for community college students (Bahr et al., 2017; Wang, 2016a). However, there is very little information available that is specific to the pathways taken by students interested pursuing a biology or biology-related degree. The work of Bahr et al. (2017) was specific to the STEM disciplines of chemistry, physics, and math, but it was descriptive and did not propose a predictive model. Additionally, Snyder and Cudney (2017) point out that most of the existing predictive models for retention in STEM are based on the characteristics of students at four-year institutions and may not be appropriate for community college populations. They conducted a review of the literature relating to predictive models of retention until graduation or transfer in STEM pathways in college environments, from the year

2000 to 2017 and found that little existed for community colleges. Snyder and Cudney (2017) suggested a validation of existing models using community college data. Subsequently, Wang (2016b) has filled in some of the gaps with her extensive work on community college transfer in STEM but not specifically for biology. This study informs the understanding of the relationship between course-taking behavior and transfer, specifically for students taking biology.

Theoretical Framework

The theoretical framework for this study is based on concepts of academic momentum (Adelman, 1999, 2006), extended by Wang (2016b) as the STEM transfer model. This model was informed by elements of social cognitive career theory (Lent & Brown, 2019; Lent et al., 1994), which is based in part on findings of the effect of proximal goal setting on the intrinsic motivation and self-efficacy components of social cognitive theory (Bandura & Schunk, 1981). This study adds specific information from the STEM discipline of biology to inform the curricular domain of the model, including patterns of course-taking behavior.

Academic Momentum

Adelman's seminal works documenting the relationship of longitudinal patterns of college course-taking behavior to student degree completion for both students at four-year institutions and community colleges, support the academic momentum framework (Adelman, 1999; Adelman, 2005; Adelman, 2006). The resulting model that suggested degree completion for undergraduates was influenced not by discrete variables in isolation but by the cumulative and interactive effect of the characteristics of the student's entry into college and by course load and subsequent course-taking patterns, particularly in the early stages of a college experience. Adelman (1999, 2005, 2006) identified categories of contributors to academic momentum, including, academic resources (a composite of high school courses, test scores, and class rank), timing of college entry, credit accumulation in the first year, and attendance patterns, including enrolling during summer months. Adelman's work, based on national data from the National Center for Education Statistics (NCES) and the National Education Longitudinal Study (NELS) for 1982-1993 and 1992-2000 cohorts of students, described correlations between contributing factors and degree completion (Adelman, 1999, 2006).

To extend the academic momentum framework, Attewell et al. (2012) used transcripts from the NELS 1988-2000 cohort of students to construct predictive growth curve models using four different aspects of academic momentum: timing of college entry, attendance pattern, high first term credit load, and summer attendance. Curves were constructed for students who began at a four-year institution as well as at a community college. Attewell et al. (2012) critiqued Adelman's (1999, 2006) construction of the categories of momentum, noting that cause and effect were conflated in some of the categories (e.g. student grades represented an effect) and suggested they should excluded. Based on this critique, Attewell et al. (2012) altered the momentum categories to represent credits attempted and not the ratio of credits attempted and completed, they did not adjust for courses withdrawn or failed, they included remedial coursework, and they found that the similar growth curves for four-year institutions and community colleges supported the predictive value of the academic momentum framework. Findings of this research indicated that late college entry and part-time attendance were significant negative predictors of college completion (Attewell et al., 2012). Additionally, summer attendance was a significant positive predictor, and high credit loads were not a significant predictor of college completion (Attewell et al., 2012). The shift from conceptualizing academic momentum as descriptive to predictive tool highlights the need to inform the models with an understanding of elements of academic momentum in the context of different institutions, disciplines, and student socio-demographics.

This conceptualization of academic momentum has been characterized as the rate of credit accumulation driving the speed of progress towards completion (Attewell & Monaghan, 2016). Adelman (1999, 2006) did not attempt to explain why early college momentum was essential and was careful to point out that his findings were correlational and not causal. Attewell et al. (2012) proposed several non-mutually exclusive mechanisms, suggesting that taking more courses is a route to social integration (Tinto, 2012) or that early success in college course work reinforces self-efficacy (Bandura, 1997). Still, their work does not explicitly address any of these ideas. Later more STEM specific models (Wang, 2013b, 2016b) address some of the cognitive domains and some elements of causality. To advance an understanding of potential causal mechanisms more work is needed to understand how the relationship between the elements of academic momentum and specific institutional and disciplinary contexts.

STEM Transfer Model

The second theoretical framework grounding this study is the STEM transfer model (Wang, 2016b), which builds on the elements of academic momentum that connect the trajectory of course-taking behavior to eventual student degree completion by acknowledging the role of prior attitudes, the development of self-efficacy, and outcome expectations on academic decision-making processes (Wang, 2016b). Based on social cognitive career theory (Lent et al., 1994), which relates academic or career choices to interests, self-efficacy, and outcome expectations, the STEM transfer model (Wang, 2016b) connects a student's academic trajectory towards successful transfer and attainment of a STEM baccalaureate degree to the cumulative and interrelated effects of their *person inputs* and their experiences in higher education (Wang, 2016b). Person inputs refer to socio-demographic variables, initial attitudes, and existing academic abilities (Lent et al., 1994; Wang, 2016b). These variables are similar but not identical to Adelman's (1999, 2006) constructs of academic resources, educational aspirations, and demographic variables. Adelman (2006) states, "This is a question about completion of academic credentials—the culmination of opportunity, advisement, choice, effort, and commitment" (p. 9). What he does not address is how educational experiences can affect undergraduate choice and commitment. Wang's (2016b) STEM transfer model includes aspects of the students' experiences in the classroom into the theoretical framework. This framework is also informed by the details of the specific context of the program and the institution. These elements combine the details of the student's course-taking behavior that creates STEM specific momentum (Wang, 2015) that in turn affects self-efficacy in STEM and outcome expectations regarding STEM and STEM transfer.

Consistent with social cognitive career theory (Lent et al., 1994), an increase in self-efficacy and positive outcome expectations translate into persistence and intent to transfer in STEM. The trajectory towards successful baccalaureate degree completion is then influenced by the learning experiences and contextual factors at the receiving institution (Wang, 2016b). The proposed study would build on existing empirical studies in STEM, informing this model by adding contextual data about the course-taking patterns in the STEM discipline of biology at a large western community college. The goal would be to determine if the patterns of leading indicators of STEM momentum that are predictive of transfer success in the academic momentum literature are consistent for the discipline of biology.

Summary

Reform initiatives to diversify participation in science, technology, engineering, and math (STEM) fields (Belfield et al., 2019) need to be informed by information specific to institutional, discipline and socio-demographic context. Investigating the impact of course-taking patterns of community college students enrolled in biology courses on transfer into a biology-related degree field at four-year institutions would inform curriculum development, biology transfer maps in a guided pathways reform initiative, and support services related to advising community college students in STEM. The literature review in Chapter 2 provides a summary of the challenges in measuring community college student success and previously identified metrics that are early indicators for student success, including the impact of course-taking behavior. The research outlining what is currently known about the patterns of course-taking behavior in STEM is reviewed, highlighting the gap between the impact of course-taking behavior in STEM and what is known specifically about the STEM discipline of biology. Chapter 3 describes how descriptive statistics, and multinomial logistic regression will be used to describe the course-taking patterns in biology and their relationship to student transfer success. Chapter 4 describes the results of the study, and Chapter 5 provides a discussion of the results and suggestions for applications and further research.

Chapter 2: Literature Review

This chapter reviews the literature related to the relationship of course-taking patterns for community college students and successful transfer into a STEM related degree as it relates to this study. The context for investigating transfer as a measure of success is provided in this review of the challenges of defining and tracking community college student success. This review will further explore how academic momentum has been conceptualized, including the existing research on leading indicators that may predict transfer, both for the general population of community college students and for those in STEM, to build the case for investigating the relationships in biology. The literature informing the understanding of how course-taking patterns in STEM relate to successful transfer is included to further illuminate the research gap. For the purposes of this study, transfer is defined as enrolling in a four-year institution after taking the biology class that is the first in the sequence for majors. These findings inform curriculum development, biology transfer maps in a guided pathways reform initiative, and support services related to advising community college students in science, technology, engineering, and math (STEM).

Understanding the role of community colleges in democratizing education by providing affordable access to transfer pathways and opportunities for closing the opportunity gap for historically underserved students is complicated by the difficulty in defining and tracking student success (Bailey et al., 2015; Juszkiewicz, 2019; Voluntary Framework For Accountability [VFA], 2019). Given that student success in many states is now tied to funding, much effort has gone into trying to document success in ways appropriate for community colleges. Considerations, such as the length of time that students should be tracked, the details of who should be tracked, and how to define success, have informed a variety of metrics (Juszkiewicz, 2019; Phillippe, 2019; VFA, 2019). Theoretical frameworks centered on academic momentum have guided the construction of a variety of leading indicators to help track the success of reform initiatives (Adelman, 1999, 2006; Attewell et al., 2012). In this effort, research on leading indicators of early academic momentum, such as credit accumulation, gateway course completion, persistence, continuous enrollment, and program-specific indicators, has helped establish the predictive value of these measures (Belfield et al., 2019; Witteveen & Attewell, 2017).

Additionally, research related to measures of early academic momentum has resulted in an appreciation of the importance of context. There is evidence that the predictive value of metrics can vary based on socio-demographic student variables and program variables (Belfield et al., 2016; Calcagno et al., 2008; Wang, 2016a). The evidence that the predictive value of academic momentum metrics can be program-specific has resulted in the extension of the academic momentum framework to inform community college STEM momentum and a STEM transfer model (Wang, 2016b). More research is needed to understand how this model can help inform initiatives to improve community college student success, particularly in STEM disciplines.

Defining Success for Community College Students

Defining success for community college students is complex (Bailey et al., 2015; Ginder et al., 2018; Juszkiewicz, 2019; Taylor & Jain, 2017; VFA, 2019). Compliance with the reporting requirements of the Student Right-to-Know and Campus Security Act (PL-101-542) of 1990 requires all institutions of higher learning who are eligible for federal funding (Title IV) to report to the U.S. Department of Education. The Integrated Postsecondary Education Data System (IPEDS) graduation rate represents the standard reporting of those data (Juszkiewicz, 2019). This standard utilizes a cohort of first-time, full-time, degree-seeking, college students tracked for 150% of the expected time to achieve a credential: six years for a baccalaureate and three years for an associate's degree (Juszkiewicz, 2019). However, these tracking time frames, and student profiles do not capture a community college population well. Many community college students are returning to college and are not first-time students; in the 2009-10 cohort of degree-seeking students enrolled at public two-year institutions, combining full-time and part-time, 53% were not first-time students (Ginder et al., 2018). Additionally, more than half of the students (57%) in the 2009-10 cohort of degree seeking students from public two-year institutions were attending part-time (Ginder et al., 2018). Students also often transfer between community colleges as well as to four-year schools before completing a credential (Taylor & Jain, 2017). Completion for these students is not captured using IPEDS graduation rates (Juszkiewicz, 2019). Recognizing the limitations of the various reporting structures is important for interpreting the value of different metrics for community college success.

Documenting student success appropriately is a concern, especially in states where the focus on accountability in education has resulted in a portion of the state funding being contingent on measures of student success (Offenstein & Shulock, 2010). The response has been the development of additional measures to more accurately capture student success at a community college. For example, the NSC community college completion rate is calculated after tracking full-time students for six years instead of three. The differences in the way data are captured results in very different pictures of student outcomes; the IPEDS graduation rate for community colleges for the 2009-10 cohort was almost 27%, and the NSC graduation rate was 61% (Juszkiewicz, 2019). These types of data and other aspects of the complexity of tracking community college success also led in 2018 the addition of Outcome Measures (OM) to IPEDS (Ginder et al., 2018) and the creation of a new database specific to community college needs, the Voluntary Framework for Accountability (VFA) (Phillippe, 2019; VFA 2019). Outcome Measures expand the students tracked from the standard cohort of first-time, full-time students to include first-time, part-time, and non-first-time, full-time as well as non-first-time, part-time students (Ginder et al., 2018). The completion rate for the 2009-10 cohort of first-time, full-time degree-seeking students at two-year public institutions was almost 30% compared to 38% for non-first-time, full-time degree-seeking students (Ginder et al., 2018). These completion rates were higher than the rates for comparable part-time students, which were 16% and 21% respectively. These differences help to illustrate how the multiple ways of defining completion and the heterogeneity of the student population makes defining success for community college students complex.

Other aspects of the complexity of the community college landscape are accounted for by the VFA (Phillippe, 2019; VFA 2019). Many community college students will also not be attending with the intent to earn a transfer degree. For instance, community colleges also provide students with the opportunity to earn post-baccalaureate prerequisite courses for entry into professional programs, the opportunity to attend college for personal enrichment, high school completion, and the chance to earn a terminal associate degree in a career and technical field. In 2009, a collaboration between the Association of Community Colleges and the College Board resulted in the creation of the VFA to gather data and to produce more appropriate measures of community college success, including metrics that help assess the developmental progress of institutions, some of which are implementing guided pathways (Phillippe, 2019; VFA 2019). Participation in the VFA is not comprehensive, but to date, over 200 institutions are participating (VFA, 2019). Nine student outcome measures, reported after six years for a cohort of students who entered the institution for the first time are: (a) attainment of a baccalaureate degree, (b) attainment of an associate degree, (c) attainment of a certificate, (d) transfer after the award of community college credential, (e) no transfer after award of community college credential, (f) transfer with no award of community college credential, (g) still enrolled during sixth academic year, (h) not still enrolled after sixth academic year, or (i) if not still enrolled whether the student earned more than 30 credits, or less than 30 credits is also tracked. VFA metrics include: completion; persistence for the entire cohort; persistence for students identified as credential seeking; first-time in college cohort compared to the main cohort; reached credit threshold after one and two years; successful completion of college-level Math; successful completion of college-level English; and fall to next term retention (Phillippe, 2019; VFA, 2019). Choosing the most appropriate way of measuring success at a community college is critical to assessing the efficacy of reform initiatives.

Transfer to a four-year institution can be a measure of success for community college students who enroll with the intent to earn a baccalaureate degree. It is essential to consider transfer as well as associate degree completion when considering community college success because most students will transfer to a four-year institution without earning an associate degree or a certificate. For the fall 2012 cohort of first-time degree-seeking students who began at a community college, 61% transferred without earning an associate degree (Shapiro et al., 2017a). Tracking transfer is complicated because, as Taylor and Jain (2017) point out, there are different kinds of transfer within the community college landscape. Upward or vertical transfer from a community college to a four-year institution is just one of the possible trajectories. Students also transfer horizontally from community college to community college (Goldrick-Rab, 2006; Taylor & Jain, 2017). Adelman (2006) reports that for a cohort of students studied for the 1992-2000 period, vertical transfer had a significantly positive association ($p < .05$) with baccalaureate degree completion and horizontal transfer had a significantly negative association with baccalaureate degree completion ($p < .05$). Additionally, students can reverse transfer, which describes movement from a four-year institution to a community college. A reverse transfer can also refer to the policy of sending transcripts of students who have not completed at a four-year institution back to a community college for awarding an associate degree. Recently, reverse transfer has also referred to the practice of retroactively awarding an associate degree to students who move from a community college to a four-year institution without earning an associate degree but who subsequently earned the appropriate credits (Schudde & Grodsky, 2018). This practice increases the number of community college students who appear to have completed a degree. It is essential to distinguish between different measures of success to be able to discern when higher success rates reflect a change in the method for capturing success or when they reflect improvements in student outcomes due to successful institutional reform.

The Role of Leading Indicators

Assessing the efficacy of reform initiatives at a community college is often done by tracking degree completion or transfer rates (Bailey et al., 2018). Although these measures are important, they are lagging indicators. Jenkins and Bailey (2017) suggest that lagging indicators may not provide timely enough information to let an institution make the necessary adjustments during the reform process to optimize success. They and others suggest that short term measures based on leading indicators of the success of institutional initiatives can be more valuable for optimizing the success of reform initiatives (Belfield et al., 2019; Jenkins & Bailey, 2017; Offenstein et al., 2010). Offenstein and Shulock (2010) draw a distinction between milestones, which are "specific educational achievements that students must accomplish to get from their beginning point to completion of an educational program, as well as those achievements that mark the end of the educational program" (p. 6) and success or leading indicators which are "academic behaviors that increase a student's chances of completion but are not strictly required in order to finish an academic program" (p. 6). The same measures may be present in each, such as completion of a college-level math class. Distinguishing between a milestone and a leading indicator can often be done by adding the time frame in which the milestone was achieved, such as completion of a college-level math class within the first year. Adding an element of time gives a measure of the student's academic momentum towards their educational goal (Offenstein & Shulock, 2010).

Academic Momentum

The academic momentum framework is supported by Adelman's (1999, 2005, 2006) seminal works documenting the relationship of longitudinal patterns of college course-taking behavior to student degree completion for both students at four-year institutions and community colleges. He proposed a model that suggested degree completion for undergraduates was influenced not by discrete variables in isolation but by the cumulative and interactive effect of the characteristics of the student's entry into college and by course load and subsequent course-taking patterns, particularly in the early stages of a college experience. Adelman identified categories of contributors to academic momentum including, academic resources (a composite of high school courses, test scores, and class rank), timing of college entry, credit accumulation in the first year, and attendance patterns, including enrolling during summer months. Adelman's work, based on national data from the National Center for Education Statistics (NCES) and the National Education Longitudinal Study (NELS) for 1982-1993 and 1992-2000 cohorts of students, described correlations between contributing factors and degree completion (Adelman, 1999, 2006). Adelman's descriptive work was the basis of future work on academic momentum.

To extend the academic momentum framework, Attewell et al. (2012) used transcripts from the NELS 1988-2000 cohort of students to construct predictive growth curve models using four different aspects of academic momentum: timing of college entry, attendance pattern, high first term credit load, and summer attendance.

Curves were constructed for students who began at a four-year institution as well as at a community college. Attewell et al. (2012) critiqued Adelman's (1999, 2006) construction of the categories of momentum, noting that cause and effect were conflated in some of the categories. For example, student grades represented an effect and suggested they should not be included. In their subsequent work, Attewell et al. (2012) altered the momentum categories to represent credits attempted and not the ratio of credits attempted and completed; they did not adjust for courses withdrawn or failed, included remedial coursework, and found that the similar growth curves for four-year institutions and community colleges supported the predictive value of the academic momentum framework. Findings indicated that late college entry and part-time attendance were significant negative predictors of college completion. Additionally, summer attendance was a significant positive predictor, and high credit loads were not a significant predictor of college completion (Attewell et al., 2012). The extension of the academic momentum framework in the construction of predictive models raises additional questions about the applicability of those models to heterogenous groups of students.

This conceptualization of academic momentum has been characterized as the rate of credit accumulation driving the speed of progress towards completion (Attewell & Monaghan, 2016). Adelman (1999, 2006) did not attempt to explain why early college momentum was important and was careful to point out that his findings were correlational and not causal. Attewell et al. (2012) propose several non-mutually exclusive mechanisms, suggesting that taking more courses is a route to social integration (Tinto, 2012) or that early success in college course work reinforces self-efficacy (Bandura, 1997), but their work does not explicitly address any of these ideas.

Identifying Leading Indicators of Academic Momentum

Many community colleges are adopting guided pathways models of institutional reform (Bailey et al., 2015, 2018) using different elements of Adelman's concept of academic momentum to identify leading indicators to assess the efficacy of those efforts. Belfield et al. (2019) proposed the following categories of early momentum metrics to serve as leading indicators of success for guided pathways institutional reform: credit accumulation, completion of gateway courses, and persistence. In a study looking at student transcripts from 75 community colleges in three states, Belfield et al. (2019) assessed nine different measures to validate these three categories as appropriate indicators of academic momentum. Student transcripts were assessed, and when compared against a baseline, students who met the benchmarks for leading indicators were more likely to complete a credential. These results, based on students from community colleges, are consistent with previous research from a 4-year institution (Witteveen & Attewell, 2017). Using similar but not identical indicators of academic momentum, such as credit accumulation, remedial coursework and grade point average, Witteveen and Attewell (2017) developed a data mining technique using a hidden Markov model, which incorporated the relationships between course outcomes and course-taking sequences, which allowed them to predict whether a student would graduate or not using only a few semesters of transcript data. While the leading indicators were predictive of success, there was also a relationship between whether a student graduated or not and the pattern of STEM course-taking.

Graduating students were more likely to alternate high credit loads with STEM course loads (Witteveen & Attewell, 2017). These findings have implications for effective advising and suggest that additional work exploring the relationship of leading indicators and other course-taking patterns to student success in areas like STEM would be valuable.

Credit Accumulation Momentum

Multiple authors have found that timely accumulation of credits in the first year is a good predictor of success and contributes to academic momentum (Adelman, 2005; Belfield et al., 2016; Calcagno et al., 2007; Clovis & Chang, 2019; Davidson, 2015; Whissemore, 2019). Belfield et al. (2019) found that 50% of students who had accumulated at least 15 college credits in their first year completed a degree, compared to the baseline average of 28%. Offenstein et al. (2010) suggested that between 20 and 30 credits completed during the first year is a good benchmark, consistent with the suggestion by Adelman (2006) in his investigation of course-taking behaviors that completion of at least 20 credits by the end of the first academic year was an important milestone. Results suggested dropping below 20 credits significantly decreased the probability of a baccalaureate degree by over 22% ($p < .01$). Students who attended part-time had difficulty accruing 30 credits by the end of the year, so in response to this tension, the VFA and others also benchmark 6 and 12 credits accrued by the first semester as well as 15, 24, and 30 credits accrued by the first year, as suggested by Belfield et al. (2019; see Offenstein & Shulock, 2010 for review of measures tracked by multiple state and multistate initiatives; Phillippe, 2019). Assessing the value of the different elements of academic momentum as leading indicators of success in particular contexts, such as in a specific STEM discipline or for a socio-demographically distinct group of students, needs to be grounded in an awareness of the nuances of each element.

There is evidence that suggests that a small difference in credit load has an impact on the momentum a student is accruing to carry them forward to completion. For financial aid status, a 12-credit load is defined as full-time, but some research suggests that even a small difference in enrollment intensity affects the predictive value of this metric. Some studies suggest there is a difference in predicting student success between taking a 12-credit or a 15-credit load in the first semester (Attewell & Monaghan, 2016; Belfield et al., 2016). In their study exploring the relationship of credit load and graduation rates, Attewell and Monaghan (2016) used propensity-score matching to control for the confounding variables (because students who take higher credit loads tend to be those who are already from socio-demographic groups who are more likely to be successful) and compared students from a national sample of first-time students entering college in 2003-04, to see if credits attempted in the first semester represented a good metric for academic momentum. These researchers found that, after an attempt to control for the confounding variables, not only was a student taking 15 credits the first semester more likely to graduate from college, the effect was more pronounced for community college students compared to students at a four-year institution. Community college students were five percentage points less likely to earn a baccalaureate degree in six years if they took 12 instead of 15 credits their first semester (Attewell & Monaghan, 2016). The positive impact of increased credit accumulation in the first semester is intuitive and raises questions of the applicability of this finding to all groups of students.

This finding is consistent with work done in the Tennessee Community College system that found students who took 15 credits in their first term were significantly ($p < .01$) more likely to complete a degree than students who took 12 credits (Belfield et al., 2016). The beneficial effect of credit momentum was significantly ($p < .01$) more pronounced for women and students from historically underserved ethnic and racial groups (Belfield et al., 2016). Interestingly, Attewell and Monaghan (2016) found that when the students in different subgroups were compared, students who worked more than 30 hours per week did not seem to receive the same graduation benefit from carrying a 15 credit course load. This finding is important since over 31% of community college students enrolled in the 2015-16 academic year worked full-time (American Association of Community Colleges [AACC], 2019). These data suggest that applying one common set of leading indicators to the heterogeneous population of students that attends community college, without understanding differences between groups, may not be the most effective way of identifying opportunities for improving outcomes. More nuanced measures that capture additional elements of a student's journey, such as calculated course completion ratios or course completion efficiency, where the number of courses completed is divided by the number of courses attempted, have also been proposed as a credit accumulation metric (Adelman, 2006; Hagedorn et al., 2007; Hagedorn & Kress, 2008).

Course Momentum

Gateway course momentum, or completion of college-level gateway courses within the first year of enrollment, is also a good leading indicator that predicts completion or transfer for community college students (Belfield et al., 2019). The usage of terms in the literature is not consistent (Hagedorn & DuBray, 2010), but in general, gateway courses refer to those that a student must pass to continue with their program of study, such as an introductory course, where the knowledge is foundational (Flanders, 2017). Sometimes the term gateway is used interchangeably with gatekeeper and sometimes the terms are differentiated. When the terms are differentiated, gatekeeper courses are those that also have to be completed for a student to continue on with a program of study but where the pass rates tend to be lower than gateway courses (Flanders, 2017; Hagedorn & DuBray, 2010). These courses then function as barriers for students.

Remedial or developmental (pre-college) Math and English courses are often gatekeeper courses, and studies have shown that women and historically underserved racial and ethnic groups tend to be overrepresented in remedial classes, enrollment in which has a negative association with successful transfer (Crisp & Delgado, 2014; Hagedorn & DuBray, 2010). Jenkins and Bailey (2017) suggest that using gateway course momentum metrics that track college level instead of pre-college course work is indicative of how much support an institution has provided to move students past the barriers of developmental education. Belfield et al. (2019) tracked completion of college English, completion of college math, as well as completion of both college

English and math in the first year and found that these leading indicators were good predictors of an associate degree or certificate attainment.

These results are consistent with the work of previous authors (Calcagno et al., 2007; Davidson, 2015; Hagedorn et al., 2008). For instance, in a study of California community college students, Hagedorn et al. (2008) also found that students who successfully transferred were twice as likely to have completed an introductory biology, chemistry, or economics course. The importance of completion of gateway courses in, addition to college math and English, was further highlighted in a study of degree-seeking community college students from a single state, where there was a greater likelihood that a student would complete a credential if they completed any of the five top-enrolled gatekeeper courses identified for the liberal arts degree: composition, pre-calculus, biology, history, computer science (Zeidenberg et al., 2012). There was no significant difference in the association with degree completion between these classes. Zeidenberg et al. (2012) note that it was possible to identify gatekeeper courses in all the programs of study within the state community college system and that these courses varied between programs. The evidence that there are differences between programs in which courses are gatekeepers raises the question of whether the role of gatekeeper courses is also different between programs or disciplines.

Leading indicators of success are not equally relevant to all student populations. Schudde and Grodsky (2018) comment that “the same community college may also affect different students in different ways" (p. 425). For example, in a study of Florida community college students, Calcagno et al. (2007) found that while older students (25-65 years) were more likely to graduate than younger students (17-20 years), the leading indicators of credit accumulation and passing the first college level math class were more important predictors of graduation for younger students. Opportunities for deploying institutional resources to support student success may arise if further study identifies other differences in the predictive value of leading indicators in the context of a specific study site or discipline.

Focusing on academic momentum, more specifically, Jenkins and Bailey (2017) propose that program momentum should be included as a leading indicator of student success, where program momentum is defined as completion of at least nine credits in a specified program of study in the first year. The relevance of program momentum was supported by the work of Jenkins and Cho (2012), who found that concentration of work in a particular program of study and early entry into a program was predictive of completion. More work is needed to understand the role of program-specific courses and identify appropriate leading indicators. The need for more work is evident in areas such as STEM where major efforts are focused to increase student success (NAS, 2019) and calls for reform of the teaching of introductory (gateway courses) have gone out at a national level (Brewer & Smith, 2011; Laursen, 2019).

Persistence Momentum

Persistence momentum metrics vary but are often based on the rate at which students remain enrolled from the first to the second term (Belfield et al., 2019). Hickman (2011) found that persistence from the first to the second term was a good predictor of student retention at the same institution in the following year. Studies of persistence and retention in a community college population are complicated by the propensity of students to horizontally transfer between institutions, and therefore they do not persist at a particular institution but are retained educationally (Taylor & Jain, 2017). Also, community college students often *stop out* or interrupt the progression of their education to take care of family or other personal issues, so their patterns of attendance are less predictable than students at four-year institutions (Hickman, 2011).

Continuous enrollment or persisting in a time frame longer than first to second term, is also an indicator of success. In a study of California community college students, Hagedorn et al. (2008) found that those who were enrolled continuously with no breaks were more likely to transfer successfully. This finding is consistent with a national study of community college students that found there was a significant positive association ($p < 0.01$) between continuous enrollment and successful transfer (Wang, 2012). Continuous full-time enrollment may be optimal, but it is not the reality for many community college students. In a study designed to describe the patterns of enrollment for a sample of 14,429 community college students, just over 1% of the students followed a pattern of continuous, full-time enrollment fall through spring for their first five semesters (Crosta, 2014). Crosta (2014) found that the students demonstrated 4,585 distinct patterns that deviated from the 'traditional' continuous, full-time enrollment fall through spring. These realities highlight the need to more fully understand the relationships between different elements of academic momentum as they vary across the literature. If the adjustments to institutional reform initiatives are made based on leading indicators of early academic momentum, there is a need to ensure that these leading indicators are appropriate for the programs and the people they are designed to support.

Leading Indicators of Academic Momentum in STEM

Some leading indicators of success in STEM have been identified in the context of the community college setting for both transfer and degree completion (Bahr et al., 2017; Hu & Ortagus, 2019; Zhang, 2019). In a study of community college students transferring to a four-year institution in Texas, students who completed college math courses, had higher GPAs, and carried higher first term credit loads in their first term at the four-year institution and were significantly ($p < .01$) more likely to complete a STEM degree than to not complete a baccalaureate degree (Zhang, 2019). Zhang (2019) used multinomial logistic regression to determine the relationship between socio-demographic characteristics, community college achievement, and attainment of a STEM baccalaureate degree, and found that females and older transfer students (greater than 24 years) were significantly less likely to obtain a STEM degree ($p < .001$ and $p < .05$ respectively) compared to a non-STEM degree. These results are contrary to the findings in a study using propensity score matching and nationally representative data from BPS: 04/09 and PETS: 09, to track STEM degree completion after six years by students beginning at a community college. In this study, females starting at a community college had a STEM degree completion rate of over 25% and males had a completion rate of just over 20% (Hu & Ortagus, 2019). Both groups had lower completion rates than their counterparts who started at four-year schools. Hu and Ortagus (2019) also found that completion of gateway courses and credit accumulation were leading indicators of early academic momentum. These data suggest that the leading indicators for early academic momentum that predict success generally for community college students are also predictive for STEM transfer student success. General patterns establishing components of academic momentum as good leading indicators of student success exist, but to facilitate broader engagement in specific STEM disciplines it is vital to understand if there are particular relationships between different student populations and specific leading indicators.

Gateway Math Momentum in STEM

Math is foundational for all STEM pathways and multiple studies have found that the level of math at which a student begins college course-taking is an important factor in transfer success for a STEM major (Cohen & Kelly, 2019b, 2020; Hagedorn & DuBray, 2010; Wang, 2016a). While the entry point for math was important, the timing of math-taking and accumulation of math credits is also related to success. For instance, Wang (2016a) found that the STEM course-taking pattern that was most often exhibited by community college students successfully transferring in STEM included the first-term completion of a transferable STEM course other than math, followed by math in a subsequent term. Additionally, results suggested that while accumulating more transferable math and non-math STEM credits contributed to the probability of transferring, patterns were different when disaggregated by gender and age (Wang, 2016a). Wang (2016a) also found that traditional-age students had a 4% increase in the probability of transfer after completing 12-24 STEM credits and 2.7-6 math credits, but there was no corresponding increase in the probability of transfer for non-traditional age students (24 years or older). Similar differences in the probability of transfer were not found based on race or ethnicity (Wang, 2016a) contrary to the results of other research (Hagedorn & DuBray, 2010).

For example, a transcript and survey analyses done by Hagedorn and Dubray (2010) using a sample of students from the Los Angeles Community College district, where the progression through math courses was tracked and compared to degree completion, and significant differences in the progression through the math sequence were found based on race and ethnicity. African-Americans and Hispanic students had significantly lower course completion ratios, and math and Science grade point averages ($p < .05$) compared to White and Asian students (Hagedorn & DuBray, 2010). The importance of the math entry point was underscored because less than 13% of the STEM-transfer aspiring students from nine community colleges entered the STEM pathway at college level math (Hagedorn & DuBray, 2010). The discrepancies between the findings of different studies may be methodological, they may also represent differences in the relationship of different student populations to math completion as a leading indicator, and more study is needed.

Course-taking Behavior in STEM

The STEM transfer model (Wang, 2016b) suggests that transfer momentum is gained not just by the completion of individual elements of a STEM pathway, for example, math, but by the cumulative effect of a student’s trajectory in that pathway. In a descriptive study of students in the community college system in California, course-taking patterns towards transfer in math, chemistry, and physics were mapped (Bahr et al., 2017). The course level at which students entered the pathway was related to transfer success in all three disciplines. Data were disaggregated by race, ethnicity, and gender. Differences in the course-taking patterns for women and students from historically disadvantaged racial or ethnic groups were found in all three disciplines.

These students tended to enter the pathways in the lower level courses compared to White male students. Women had higher pass rates for introductory courses on the first attempt for all three disciplines compared to men, but this finding did not necessarily result in similar patterns of progression. This research is consistent with earlier findings in a study of the Los Angeles community college system where women had significantly higher grades in science courses ($p < .05$) compared to males (Hagedorn & DuBray, 2010). Interestingly, in this study women had significantly higher course completion ratios for science courses than men ($p < .001$), although their study did not determine if these higher course completion ratios translated into successful transfer in a STEM major. These results suggest that there are variations within STEM disciplines and within groups of students progressing through STEM courses. More research describing the course-taking patterns of students in discipline-specific STEM transfer pathways is needed.

STEM Program Momentum

Tracking program momentum is more nuanced because the goal is to keep the student not only progressing but progressing in a discipline-specific pathway. The Jenkins and Bailey (2017) definition of at least nine credits in a program of study works well in a STEM context where there are often multiple sequences of required classes. In a study to determine what patterns of course-taking were associated with successful transfer to a four-year institution in a STEM discipline, transcript information from national databases was used to assess the course-taking patterns for 2,330 first-time community college students who completed a STEM course during their first year (Wang, 2016a). Wang (2016a) found that taking more transferrable

STEM classes and fewer classes in other course categories was related to transfer in a STEM major. The most successful course-taking pattern did not include math in the first term, indicating that the timing of course-taking is a critical element. There also seemed to be a dosage effect where earning more than 24 credits in STEM increased the likelihood of transfer in STEM, with some nuances in how many math versus other STEM discipline credits were earned. Differences in course-taking patterns emerged based on gender and age but not based on other demographic variables such as socioeconomic status, race or ethnicity (Wang, 2016a). Interestingly, students with credit concentrations in the physical sciences were more likely to transfer in STEM disciplines. This trend may have occurred because students taking other STEM classes may have been on non-transfer pathways, such as those connected to Allied Health programs, which include classes in biology. Describing course-taking for transfer in biology or a biology-related major may show patterns that are not evident in other STEM disciplines.

It is important to consider that not all community college students are accessing the transfer function, and if the institution does not require students to declare a major, it can be difficult to discern intent. Course-taking patterns may reflect differences in the initial plan to transfer as well as changes based on experience. In a study examining the course-taking patterns of 1,668 first-time community college students taking STEM courses in a Midwestern state, in their first year, Chan and Wang (2018) found that course-taking patterns subsequently followed three major tracks in the first semester that they characterized as transfer, vocational, and exploring. Students who persisted did not necessarily follow the same patterns in their second semester. Expanding on earlier work by following course-taking over a longer period, Wang et al. (2019) examined the relationship between course-taking patterns of community college students and successful transfer to four-year institutions in a STEM major. Data were collected from the Ohio Department of Higher Education's Higher Education Information System (HEI) for first-time students who started in 2003 at any of the state's 23 community colleges. A cohort of 36,618 students was followed for eight years. Cluster analysis was used to identify five general patterns of transfer. Three of the cluster groups resulted in students successfully transferring into STEM majors. These three clusters were described as concentrating on STEM coursework, or concentrating on accumulating general education credits, or combining remedial coursework with a broad range of courses outside of STEM (Wang et al., 2019).

In contrast to prior research that found that credit accumulation focused on STEM classes was predictive of successful transfer (Wang et al., 2019), this research found that the clusters most focused around taking STEM courses were not the only ones that resulted in students transferring successfully to a STEM major (Wang et al., 2019). Building a firm foundation in the general education courses required for one of the state's transfer degrees was also a viable route. Wang et al. (2019) suggest that an examination of the differences between STEM disciplines might be critical in understanding the transfer cluster groups. Also, in contrast to previous studies (Crisp & Delgado, 2014; Hagedorn & DuBray, 2010), students who began in a remedial course followed by a broad range of STEM and general education coursework were also successful, although they tended to transfer later. These findings indicate that studies that follow students for a short period may miss course-taking patterns that eventually do lead to success for community college students. These findings suggest the pathway to success for community college students in STEM may be just as complicated as defining success.

Summary

Diversifying the engagement in STEM of a broader range of students at the undergraduate level is an important goal (NSB, 2019; NSF, 2017). The transfer function of community colleges will play a critical role in meeting this goal, given the demographics of the community college population (NAS, 2019; Wang, 2015). Successful transfer rates in STEM are low, and so understanding the transfer process is key to improving STEM engagement (Bailey et al., 2015). Research suggests that course-taking behavior is important for STEM transfer success (Bahr et al., 2017; Wang et al., 2019). Existing discipline specific information suggests that not all STEM disciplines are the same (Bahr et al., 2017), and there is little detailed information available to inform transfer maps in biology. Previous research also suggests that sociodemographic factors impact student success in transfer pathways (Belfield et al., 2016; Calcagno et al., 2008; Wang, 2016b but there is a gap in the information available for students specifically engaged in a biology major course-taking sequence. Understanding course-taking patterns in biology by different groups of students may help inform initiatives to increase transfer rates.

Existing reforms such as guided pathways initiatives (Bailey et al., 2015) use leading indicators of academic momentum to predict student success but there is currently no research available to support the validity of these indicators for a population of students in a specific STEM degree sequence such as biology. Insights into these topics could inform curriculum development, biology transfer maps in a guided pathways reform initiative, and support services related to advising community college students intending to transfer and major in biology. Future chapters will outline a proposed methodology for a study to provide additional insight and fill research gaps for the discipline of biology.

Chapter 3: Methodology

The following chapter discusses the methodology used to describe the patterns of course-taking behavior of students in a biology degree-transfer sequence at a large western community college and differences disaggregated by gender age, race, and ethnicity. The process for identifying the relationship between course-taking behaviors identified as leading indicators of academic success and transfer to a four-year institution was described. This chapter includes a description of the population of students whose transcripts were evaluated, and the methods used to describe and analyze patterns in their course-taking behavior related to transfer to a four-year institution, and success in upper-division biology courses. Ethical considerations will also be discussed.

Purpose Statement

The purpose of this quantitative study was to investigate the relationship of course-taking patterns of community college students enrolled in biology courses to successful transfer into a biology or biology-related degree track at four-year institutions, by means of descriptive statistics to map student transcript information, and multinomial logistic regression. For the purposes of this study, transfer was defined as enrolling in a four-year institution. This information will help inform curriculum development, biology transfer maps in a guided pathways reform initiative, and support services related to advising community college students in science, technology, engineering, and math (STEM).

Research Questions

The specific research questions investigated included:

Research Question One

To what extent do the leading indicators that predict successful transfer to a four-year institution identified for community college students in general, also predict transfer outcomes for students in a biology transfer sequence at a large western community college?

Research Question Two

What was the pattern of course-taking behavior of students in a biology-degree transfer sequence at a large western community college?

Research Question Three

What was the pattern of course-taking behavior in a biology-degree transfer sequence for students, disaggregated by gender, age, race, and ethnicity, at a large western community college?

Research Question Four

What was the relationship between the course-taking behavior in a biology-related degree sequence and predicting transfer to a four-year institution into a biology or biology-related degree track?

Rationale for Methodology and Research Design

This non-experimental quantitative study using archival transcript data used an ex post facto design to answer four research questions. A quantitative methodology was appropriate for these research questions because the goal was to describe and establish relationships between the variables associated with the course-taking patterns of the students in this study (Mertler, 2016). Students cannot be randomly assigned to comparison groups and so a non-experimental design is appropriate (Field, 2018).

Archival transcript data were used and since no manipulation of the variables will be done after the fact, and the data were not collected originally for research, an ex post facto design is appropriate (Silva, 2010). Multiple authors have made the case that for community college students, who are often commuters and who engage with the institution in a very heterogeneous way, a transcript is a good record of their interaction with the institution and is not subject to limitations of memory and provides reliable insight into student course-taking behavior (Adelman, 2005; Hagedorn & Kress, 2008; Wang, 2016a).

Research questions one and four were investigated using multivariate multinomial logistic regression models (Field, 2018; Hosmer et al., 2013). The dependent variables of interest were discrete and categorical. There was also no reason to assume that the relationship between the independent and dependent variables of interest was linear, so a multivariate logistic regression model is an appropriate method (Muijs, 2016).

For research questions two and three, the patterns of course-taking behavior of students in a biology-degree transfer sequence at a large western community college were investigated and described using descriptive statistics, Pearson's chi-square test and a one-way analysis of variance (ANOVA) for continuous variables (Muijs, 2016).

Setting

The setting for this study was a large, public, community college in the Western U.S. Demographic characteristics for the overall student population, and students enrolled in the first course in the sequence of major's biology in the 2014/15 academic year at this community college, are presented in Table 1. A range of lower-division classes in the biological sciences are offered at this community college and the relative demographic profile of the student population taking those classes is different from the general college population, supporting the need to examine the leading indicators for student success in a discipline-specific context.

Table 1

Demographics for Large, Western Community College compared to Students Enrolled in the First Class in the Major's Biology Sequence in 2014/15

	2014/15	
Demographic Variable	All Students	Students Enrolled in First Course in Major's Biology Sequence
Student headcount	54,249	342
Average Age	30 years	26 years[a]
Sex		
Female	53%	59%
Male	47%	40%
No Report		1%
Race and Ethnicity		
Asian	7%	10%
Black/African American	6%	3%
Hispanic	10%	8%
International/Nonresident Alien	3%	3%
Multiracial	6%	6%
American Indian	1%	1%
Hawaiian/Pacific Islander	<1%	<1%
White	61%	63%
Not reported		5%

Notes. [a]students under 18 were excluded from cohort.

Values may not add up to 100% because of rounding

Participants

The data for this study were drawn from the transcripts for the population of students who signal potential interest in a biology transfer degree-track by enrolling in the first class in the major's biology sequence in the in any term, at a large, western community college in the United States, in the 2014/15 academic year. To remove high school and dual-credit students, participants under 18 years were excluded from the analyses, which excluded 12 students from the cohort of 354 students. The remaining 342 students were followed through the fall of 2020. Many of the paradigms for required federal reporting use 150% time to completion as a tracking metric; such as tracking for three years for a two-year degree. Yet, for the heterogeneous community college population, arguments have been made that this is not enough time to capture the picture of student success (Ginder et al., 2018; Juszkiewicz, 2019; Offenstein & Shulock, 2010; Phillippe, 2019). Leinbach and Jenkins (2008) argue that a five-year window for tracking community college student transfer success is optimal to balance the need to capture the success of students enrolling part-time and the practicality of using the study to inform policy decisions when the enrollment environment and student population is constantly changing. Tracking students through the 2019/20 academic year potentially included the confounding variable of the impact of COVID-19 on student course-taking and transfer behaviors for the spring of 2020 and was considered in the interpretation of the analyses.

Procedures

Data for this study came from multiple sources. Individual student transcripts for the population of students enrolled in the first class in the major's biology sequence in the three consecutive academic years, were provided by the office of Institutional Effectiveness at the large, western community college from the institution's Banner system. Banner is a type of enterprise resource planning software marketed by Ellucian (Ellucian, 2020). Data were shared with the researcher in a Microsoft Excel spreadsheet with student identifiers removed. Transcript records unique to a particular student were identified using a personal identification master (PIDM) number. A PIDM is a number assigned by Banner that links together all records in Banner but is never included on any screen or form. The transfer outcome information to match to the individual student data records came from the office of Institutional Effectiveness and a request to StudentTracker® (National Student Clearinghouse). Participants whose records were not available from the NSC to determine transfer outcomes were excluded from the analyses, reducing the sample size by two. Identifying student information was removed from the StudentTracker® records and shared with the researcher using PIDM sequences. PIDM sequences were then matched between data sets.

Data Analyses

The patterns of course-taking behavior and their relationship to transfer outcomes were explored using a combination of descriptive and inferential statistics. A summary of data analyses used to answer research questions one through five is presented in Table 2.

Table 2

Summary of Analyses for Research Questions

Research Question	Data Collected to Answer	Data Analysis Technique
1. To what extent do the leading indicators that predict successful transfer identified for community college students in general, also predict transfer outcomes for students on a biology transfer track at a large western community college?	Transfer outcomes predicted by leading indicators of academic momentum	Multinomial Logistic Regression
2. What is the pattern of course-taking behavior of students in a biology-degree transfer track at a large western community college?	College-level biology, chemistry, physics and math prior to major's biology Grades in major's biology sequences Continuity of course-taking in major's biology sequence Enrollment intensity	Descriptive statistics Pearson's Chi-square test
3. To what extent are there differences in course-taking behavior in a biology or biology-related degree transfer track for students disaggregated by gender, age, race, and ethnicity at a large western community college?	Disaggregation by age, gender, race, and ethnicity	Descriptive statistics Pearson's Chi-square test One-way ANOVA
4. What is the relationship between the course-taking behavior in a biology-related degree sequence and predicting transfer to a four-year institution in a biology or biology-related degree track?	Transfer outcomes predicted by course-taking patterns	Multinomial Logistic Regression

Data Analysis Research Question One

This study continued with an analysis of the relationship between leading indicators that predict successful transfer to a four-year institution for a general population of students (Attewell & Monaghan, 2016; Belfield et al., 2016, 2019), to determine if those indicators also predict transfer outcomes for students in a biology-degree transfer sequence. Transfer outcome was the dependent variable or outcome for fitting a multinomial logistic regression model (Field, 2018; Hosmer et al., 2013). Transfer outcome was determined using enrollment records from the NSC data query and was divided into four categories: (a) transfer to a four-year institution in a biology or biology-related degree track, (b) transfer to a four-year institution in a non-biology related degree track, (c) transfer to a professional or graduate program, or (d) not transferred within the time period tracked. The cohort of students being tracked were a mix of first-time and college students those that had complex enrollment histories. Their transfer status was tracked based on NSC records of attendance at a four-year institution after the date of enrollment in the first-term biology major's class at the large, western community college, up to and including the fall of 2020. Determination of the transfer outcome was based on NSC enrollment codes. Students who transferred into undergraduate programs were classified as being not in biology or in a biology or biology-related program. Program designation was made using the reported NCES classification of instructional program (CIP) codes for either primary or secondary major (NCES, 2020). The programs that were included as biology or biology-related were based on the crosswalk of STEM categorization and major fields of study in BPS: 96/01, NSPAS:04, and ELS:01/06 which included agriculture, agricultural sciences (CIP code 01), natural resources (CIP code 03), forestry (CIP code 03) and biological sciences (CIP code 26) and selected subjects from multi-interdisciplinary studies (CIP code 30) such as Marine Science (Chen & Weko, 2009). The health professions and related clinical sciences (CIP code 51) were not included as biology or biology-related. This is important to note because biology courses are often taken by as prerequisites by students interested in the health professions.

Predictor Variables Research Question One. The independent variables or predictors for the multinomial logistic regression model were seven leading indicators of the student's academic momentum, as identified in the literature (Adelman, 1999, 2005, 2006; Belfield et al., 2016, 2019; Calcagno et al., 2007; Clovis & Chang, 2019; Crisp & Nuñez, 2014; Davidson, 2015; Wang, 2012; Whissemore, 2019) (see Table 3) and fit to the logistic regression model using purposeful selection (Bursac et al., 2008; Hosmer et al., 2013). These included: (a) accumulation of college-level credit in the first term, (b) accumulation of college-level credit in the first year, (c) completion of college-level math in the first year, (d) first-term grade point average, (e) completion of introductory major's biology (a STEM gatekeeper course) in the first year, (f) college-level credit accumulation in courses specific to a biology transfer degree track, and (g) enrollment intensity in the first year. Accumulation of college credit was determined as passing a course at the 100 or above level with a C grade or better. Completion of college-level math in the first year was determined using course-taking patterns in the transcript. Completion of introductory major's biology in the first year was determined using transcript records showing a grade of a C or better for the first class in the major's sequence. Courses repeated for a higher grade in the time-period examined were not included. Grade point average was calculated based on all courses, including remedial courses, for which a grade was received, this did not include courses for which a P grade was recorded. To compute an average, the numerical value of four for an A, three for a B, two for a C and one for a D grade was used. Plus or minus grades were not assigned at the institution of record. The accumulation of college-level credit in the biology transfer degree track was determined using the major's transfer map (MTM) as defined by the list of courses identified in the statewide course articulation agreement for biology (HECC, 2020). Cut points were not used due to the challenge of converting term and semester credits. Enrollment intensity was determined using the number of credits attempted by the student in the first year using the transcript data. Categories were based on the financial aid criteria followed by the community college, consistent with federal financial aid guidelines. Full-time was 36 or more credits, three-quarter time was 27 to 35 credits, half-time was 18 to 26 credits and less than half-time was less than 18 credits. Credits attempted were determined based on four terms of enrollment. Students did not all begin in the fall term so start dates were staggered. Student enrollment intensity may also not have been consistent term to term in the first year. The enrollment intensity calculation was designed to reflect academic momentum of the student and not financial aid eligibility.

The cohort tracked included post-traditional students, some of whom had a long relationship with the community college and reflected course-taking for shifting educational goals. For the purposes of this study, students who had attended the large western community college, then completed a bachelor's degree and returned to take more classes, had their transcript 'start' date assessed as the first term back at the community college post-bachelor's degree. If a student had a course-taking gap greater than seven years in their transcript, the earlier courses were not included in the analysis and the 'first year' was recorded as the first term of course taking after the gap. A 'year' of courses was calculated as four terms including the 'first' term of course taking.

Table 3

Leading Indicator Variables Coded for Multinomial Logistic Regression

Variable	Variable Description
Transfer outcome category	0 = No Transfer; 1 = Transfer Biology or Biology-related Program; 2 = Transfer Non-Biology; 3 = Transfer Professional or Graduate Program
College level credits first term (completed with a C or better)	Continuous: range 0 – 18 credits
College level credits first year (completed with a C or better)	Continuous: range 0 – 65 credits
Completion of college level math by end of first year	0 = No; 1 = Yes
Completion of first course in major's biology sequence in the first year (with a C or better)	0 = No; 1 = Yes
Program credits in biology major transfer map completed first year (with a C or better)	Continuous: range 0 - 55
Enrollment intensity first year (all credits attempted including pre-college)	Low (<18) = 0; Half (18 -<27) = 1; Quarter (27 - <36) =2; Full (≥36 credits) = 3
Grade point average first term	0.00 – 4.00

Data Analyses Research Question Two

This study began with an exploration of the pattern of course-taking behavior of students enrolled in the first course in a major's biology sequence in the 2014/15 academic year using descriptive statistics. Following previous work using a deconstructive approach to mapping course-taking the STEM disciplines of chemistry, math, and physics for the California community college system (Bahr et al., 2017), the following were mapped using transcript data from students enrolled in the first class of the major's biology sequence:

- The biology coursework prior to entry into the major's biology sequence;
- The chemistry coursework prior to entry into the major's biology sequence (the first class has a chemistry co-requisite)
- The physics coursework prior to entry into the major's biology sequence;
- The pre-college and college math coursework prior to entry into the major's biology sequence (the first class has a math pre-requisite of Intermediate Algebra, which is one level below college Algebra);
- The relationship between prior biology, chemistry, math and physics coursework and passing the first course in the major's biology with a C or better;
- The relationship between prior biology, chemistry, math and physics coursework and the grade distribution in the first course in the major's biology with a C or better;
- The continuity of course-taking in the major's biology sequence;
- Enrollment intensity during the term the first course in the major's biology sequence was attempted.

Data Analysis Research Question Three

Differences in course-taking behavior in a biology or biology-related degree transfer track for students disaggregated by gender, age, and race, and ethnicity at a large western community college were described by disaggregating data gathered from student transcripts for research question one. Student course-taking behaviors were disaggregated by gender using the binary categories of male and female. Not all students identified as male or female, but to maintain confidentiality, students who did not report were not included in the data disaggregated by gender. The information for these students was retained in other analyses. Student birth year was used to calculate age in 2014 and participants were categorized into three age categories. Age categories represented traditional-age college students who are those 23 years and younger, as well as two categories to post-traditional age students; 24 to 29 years and 30 years and older. The range of ages designated as traditional-age varies slightly in the literature to and the upper end of the age category ranges from 23 to 25. Given that the community college represented in the study does not offer upper division courses and would typically serve a traditional age population at the beginning of their college career the lower end of the range and the age categories suggested by Wang et al. (2018) were adopted for the analyses in this study. These categories are also consistent with those proposed in the statistical profiles of undergraduate populations where the age cutoff for traditional college students was based on the classification of dependent status for financial aid purposes (Horn & Nevill, 2006) Students were categorized using self-reported categories of identity using NCES guidelines (NCES, n.d.). The representation in some of the categories was low and so to preserve student confidentiality, data were aggregated for categories where the initial sample was less than 10 cases. The category designated American Indian and Other Races/Ethnicities represents students who identified as American Indian, Hawaiian or Pacific Islander and non-resident alien. Consideration for collapsing categories was based on numerical considerations, recognizing the categories as a reflection of the self-reported identity of the student as a reflection of a social experience (Ross et al., 2020). The ex post facto design of the study limited the options because respondents were only given the option of a discrete set of categories and within group homogeneity should not be assumed (Manly, 2006). Analyses were carried out using IBM SPSS.

Data Analysis Research Question Four

The relationship between the STEM courses taken and transfer in a biology-degree transfer sequence was be investigated using multivariate multinomial logistic regression (Field, 2018). Multinomial logistic regression allowed examination of a series of predictor variables associated with student demographics and course-taking behavior to determine the relationship to transfer. The dependent variable or outcome was transfer outcome in four categories: transfer to a four-year institution in a biology or biology-related degree track, or transfer to a four-year institution in a non-biology related degree track, transfer to a graduate or professional degree program or not transferred within the time period tracked. The independent or predictor variables examined for the model included the course-taking behaviors described in research question two: prior, coursework in biology, grade for the first attempt at the first course in the major's biology sequence, chemistry and math, enrollment intensity, continuity through the major's biology sequence, and demographic variables (see Table 4). Analyses were carried out using IBM SPSS.

Table 4

Course-taking Variables Coded for Fitting Multinomial Logistic Regression

Variable	Variable Description
Transfer Outcome Category	0 = No Transfer; 1 = Transfer Biology or Biology-related Program; 2 = Transfer Not Biology; 3 = Transfer Professional or Graduate Program
Credits 100-level biology	Continuous: range 1 to 25 credits
Credits 200-level biology	Continuous: range 0 to 20 credits
Credits 100-level chemistry	Continuous: range 0 to 19 credits
Credits 200-level chemistry	Continuous: range 0 to 30 credits
Credits 100-level physics	Continuous: range 0 to 4 credits
Credits 200-level physics	Continuous: range 0 to 15 credits
Credits pre-college math	Continuous: 0 to 16 credits
Credits 100-level math	Continuous: range 0 to 14 credits
Credits 200-level math	Continuous: 0 to 23 credits
Continuity between first attempt first course and first attempt second course in major's biology	Continuous: 0 to 81
Enrollment intensity term first attempted major's biology	Continuous: range 5 to 19 credits
Grade first attempt first course major's biology	0 = D, F, W, NP, and I; 1 = C, 2 = B, 3 = A
Age category	0 = ≤23 years, 1 = 24-29 years, 2 = ≥30 years
Gender	0 = Female, 1 = Male
Race and ethnicity	0 = White, 2 = Asian, 3 = Hispanic, 4 = Not Reported, 5 =American Indian and Other Races/Ethnicities[a], 6 = Black/African American

Notes. [a] Categories of race and ethnicity with 9 cases or less were aggregated to preserve confidentiality and include American Indian, Hawaiian Pacific Islander and nonresident aliens

Ethical Considerations

This study was reviewed by the Institutional Review Board (IRB) at the University of Portland. The approval letter and materials for the IRB at the University of Portland was shared with large western community college that is the setting for the study and further security protocols reviewed. Confidentiality of the participants was maintained by assigning each student a random code and any identifying information will not be included in the reporting. Disaggregated data that resulted in small enough sample sizes to potentially reveal the identity of the student was omitted from the reporting to preserve confidentiality.

Summary

This study investigated the impact of course-taking patterns of community college students enrolled in biology courses on successful transfer into a biology-related degree field at four-year institutions. A cohort of students from a large, western community college enrolled in the major's biology course sequence in 2014/15 was tracked and the entry into the sequence, exit out of the sequence and transfer outcomes was described using descriptive statistics. Inferential statistics were used to determine the relationship between early indicators of academic success and transfer for the same cohort of students. Chapter four documents the results of this study. Chapter five includes a discussion of the results. Including how this information may inform curriculum development, biology transfer maps in a guided pathways reform initiative, and support services related to advising community college students in biology, directions for future research and limitations.

Chapter 4: Results

This chapter reports the data analyses for an examination of the relationship between course-taking patterns for students in in undergraduate biology and community college transfer-success. This relationship was explored for a group of students enrolled in the first course in the major's biology sequence during the 2014/15 academic year at a large, western community college. The analyses are organized around four research questions: (a) To what extent do the leading indicators that predict successful transfer to a four-year institution identified for community college students in general, also predict transfer outcomes for students in a biology transfer sequence at a large western community college? (b) What is the pattern of course-taking behavior of students in a biology-degree transfer sequence at a large western community college? (c) What is the pattern of course-taking behavior in a biology-degree transfer sequence for students disaggregated by gender, age, race, and ethnicity at a large community college in the west? and (d) What is the relationship between the course-taking behavior in a biology-related degree sequence and transfer to a four-year institution in a biology or biology-related degree track? The predictive value for transfer outcomes for the leading indicators of academic momentum (credit accumulation in the first term, first year, and in the biology major's transfer map, first-year grade point average, passing college math in the first year, passing major's biology in the first year, and first-year enrollment intensity) are fit to a logistic regression model. Aspects of course-taking examined using descriptive statistics included level of biology, chemistry, physics, and math taken prior to enrollment in the first class in the major's sequence, grade outcome, retention through the three-term sequence of major's biology, enrolment intensity, and relative timing of course-taking for sequential classes. The relationship to student outcomes in major's biology is described using a one-way ANOVA and Pearson's Chi-square tests. Data were disaggregated by gender, age, race and ethnicity. Finally, course-taking variables were fit to a logistic regression model to determine the predictive relationship to transfer outcomes.

Research Question One

The first research question was: To what extent do the leading indicators that predict successful transfer to a four-year institution identified for community college students in general, also predict transfer outcomes for students in a biology transfer sequence at a large western community college?

Transfer Outcomes Descriptive Statistics

The relationship between transfer into a biology related degree program and academic momentum for the cohort of students taking the first course in the major's biology sequence at a large western community college in the 2014/15 academic year was initially examined using descriptive statistics. Most students (72%, $n = 243$) in the cohort taking the first course in the biology major's sequence at the community college later transferred to a four-year institution. The most common outcome was transfer into a biology or biology-related degree program (see Table 5). A small group of students (3%, $n = 9$) transferred directly into a professional or graduate degree program. Interestingly, all the students in this category transferred into a program with a classification of instructional programs (CIP) code of 51, which is designated for health professions and related clinical sciences (NCES, 2020).

Table 5

Transfer Outcomes for Cohort of Students Enrolled in First Term of Major's Biology 2014/15 Academic Year as of Fall 2020 (N =336)

Transfer Outcome	*n*	%
No transfer	93	28
Transfer biology or biology-related degree program	129	38
Transfer non-biology degree program	105	31
Transfer into professional or graduate school program	9	3

Leading Indicators of Academic Momentum Descriptive Statistics

Additionally, four of the seven variables examined as leading indicators of academic momentum were continuous, including: (a) college credits completed with a C or higher in the first term, (b) college credits completed with a C or higher in the first year, (c) college credits fulfilling criteria specified by the Major's Transfer Map (MTM) outlined for biology (HECC, 2020) completed with a C or higher in the first year, and (d) first term grade point average (see Table 6).

Table 6

Descriptive Statistics for Continuous Leading Indicators of Academic Momentum for the Cohort of Students Enrolled in First Term of Major's Biology 2014/15 Academic Year as of Fall 2020 (N = 336)

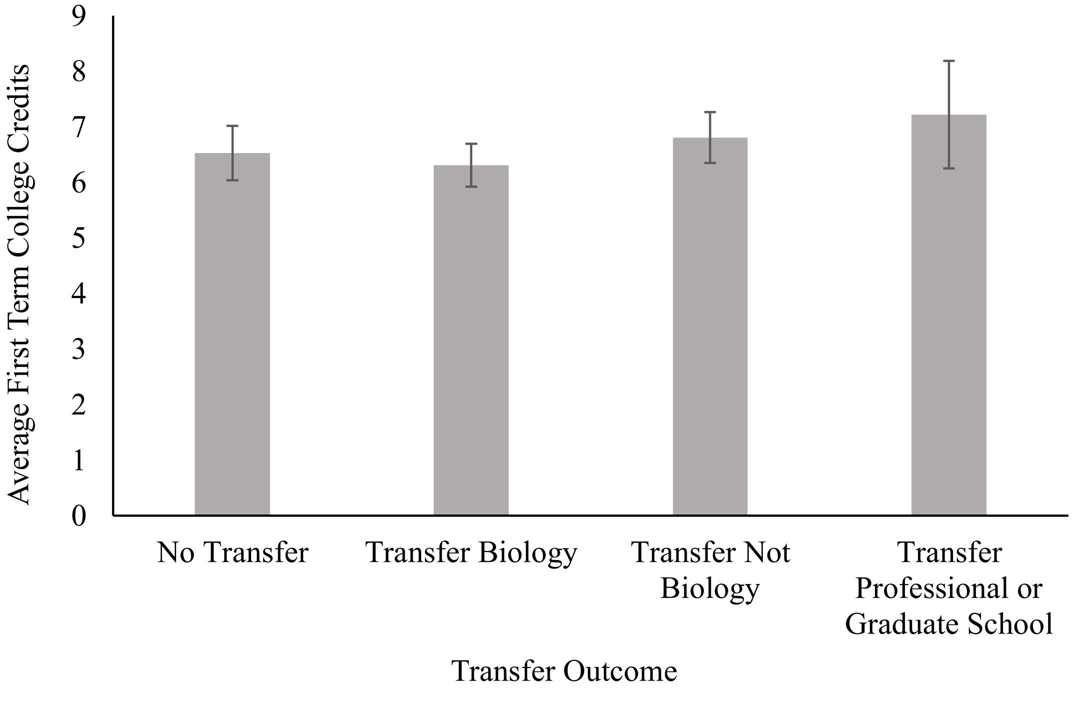
Leading Indicators of Academic Momentum	Mean	*SD*
College credits completed in the first term	6.55	4.54
College credits completed in the first year	21.85	14.38
Program credits in the biology major transfer map completed in the first year	9.38	10.53
Grade point average first term	2.94	1.29

College Credits Completed First Term

Students who transferred into a professional program or into graduate school had the highest average number of first term college credits completed with a C or better (M = 7.22, SD = 2.91), and students who transferred into biology had the lowest average number of first term college credits completed with a C or better (M = 6.31, SD = 4.39) (see Figure 1). A one-way ANOVA was used to determine that there was no significant difference in the average number of college credits accumulated in the first term between students achieving the four transfer outcomes, $F(3, 332) = .30$, $p = .83$.

Figure 1

Average Number of College Credits Completed in the First Term (±SE) (N = 336)



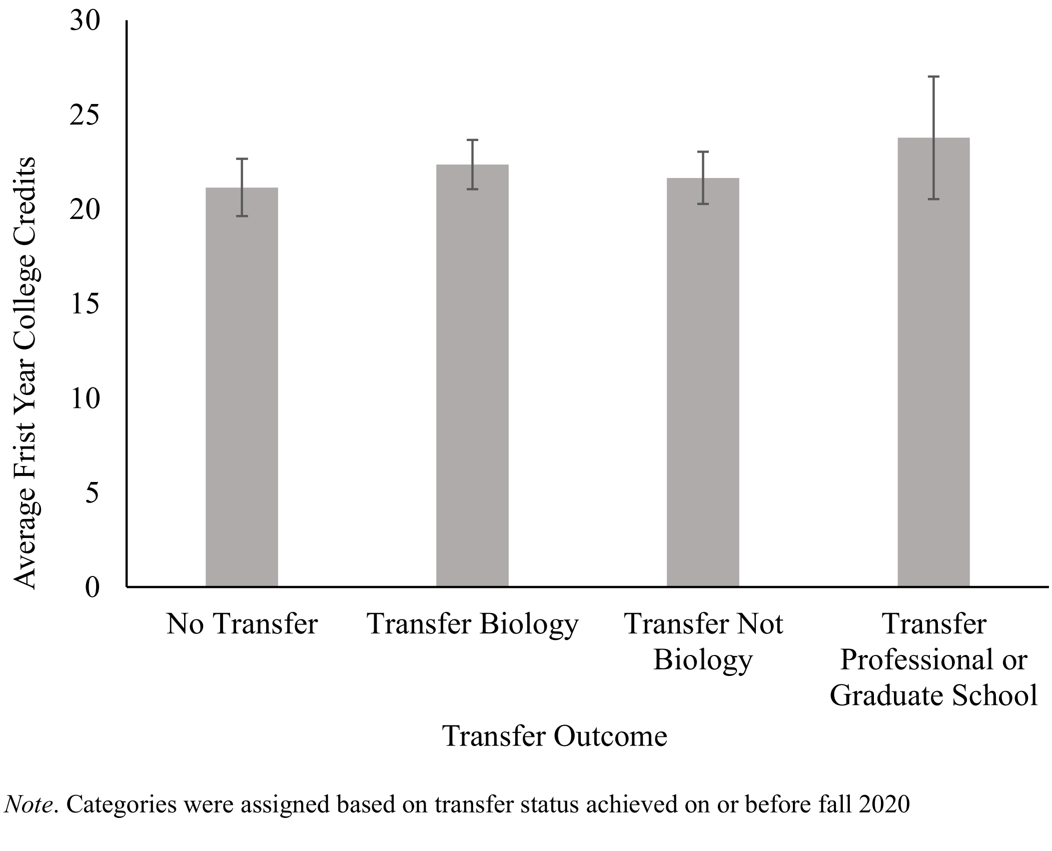
Notes. Categories were assigned based on transfer status achieved on or before fall 2020

College Credits Completed First Year

The group of students who transferred into a professional program or into graduate school also had the highest average number of first year college credits completed with a C or better (*M* = 23.78, *SD* = 9.72), and the students who did not transfer had the lowest average number of first year college credits completed with a C or better (*M* = 21.15, *SD* = 14.64) (see Figure 2). A one-way ANOVA was used to determine that there was no significant difference in the average number of college credits accumulated in the first year between students achieving the four transfer outcomes, $F(3, 332) = .19$, $p = .91$.

Figure 2

Average Number of College Credits Completed in the First Year (N = 336)



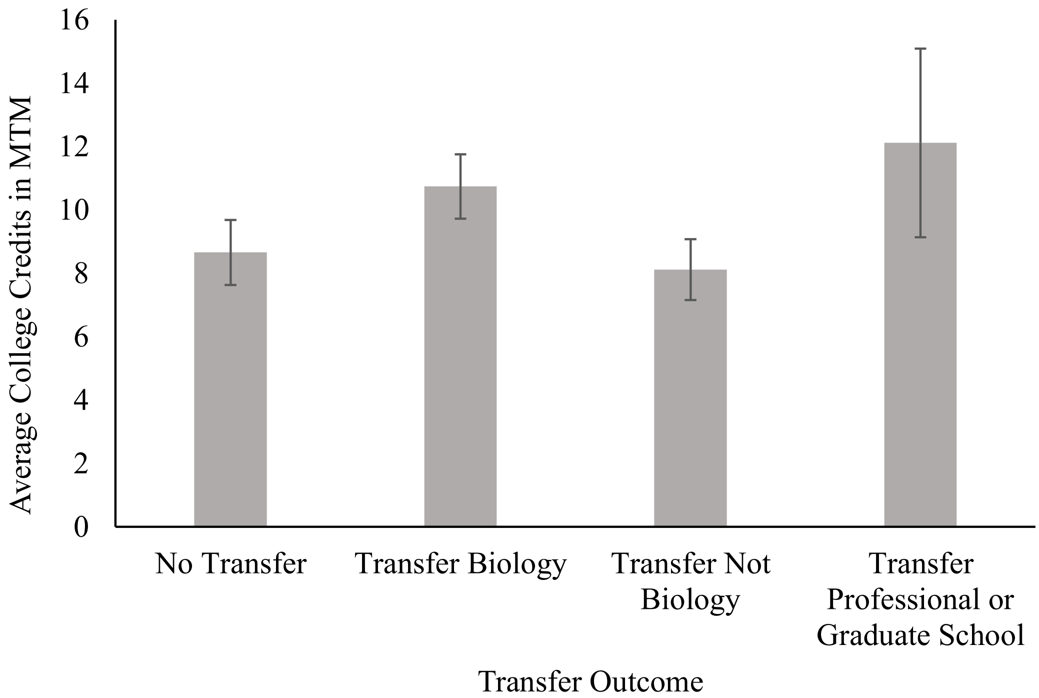
Note. Categories were assigned based on transfer status achieved on or before fall 2020

College Credits in the Major Completed in the First Year

The group of students who transferred into a professional program or into graduate school had the highest average number of first year college credits completed with a C or better in the Major's Transfer Map (*M* = 12.11, *SD* = 8.94), and the students who transferred but not in biology had lowest average number credits in this category (*M* = 8.66, *SD* = 9.86) (see Figure 3). A one-way ANOVA was used to determine that there was no significant difference in the average number of first year credits earned that could be applied to the biology major's transfer map (MTM) between students achieving the four transfer outcomes, $F(3, 332) = 1.58$, $p = .20$.

Figure 3

Average Number First Year College Credits Earned in the Major's Transfor Map for Biology ± SE by Transfer Category (N = 336)



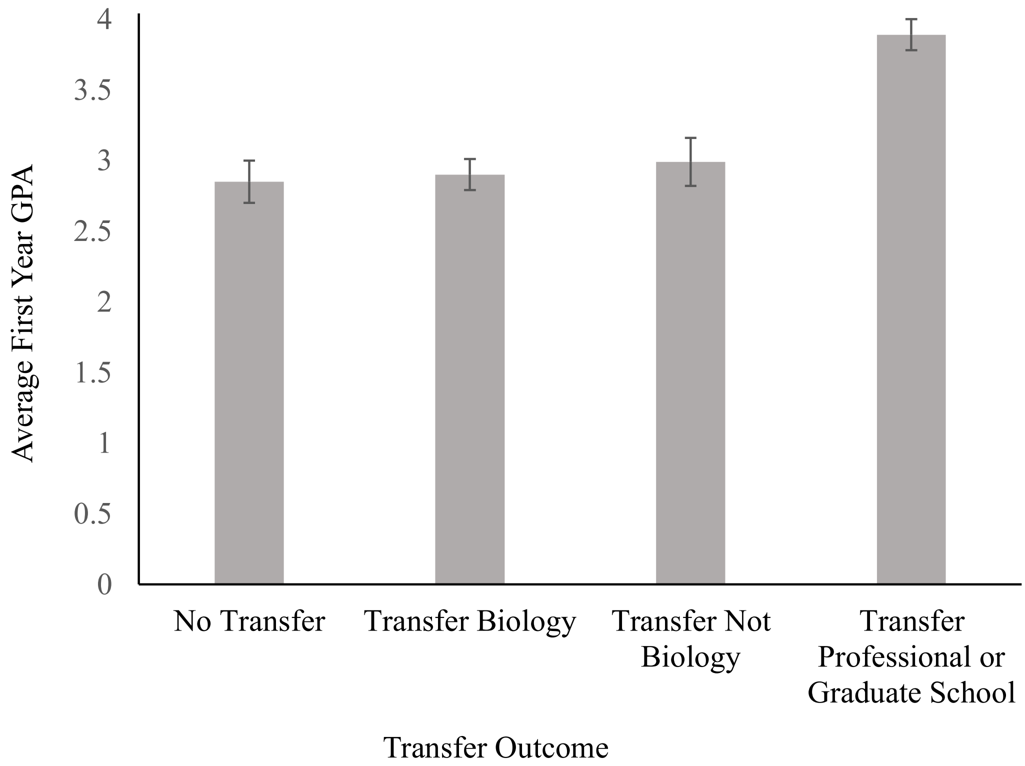
Note. Categories were assigned based on transfer status achieved on or before fall 2020

First-term GPA

The group of students who transferred into a professional program or into graduate school had the highest average first term GPA (*M* = 3.89, *SD* = .33), and the students who did not transfer had the lowest average first term GPA (*M* = 2.84, *SD* = 1.41). A one-way ANOVA indicated no significant difference in the mean first term GPA between students achieving the four transfer outcomes, $F(3, 332) = 1.87$, $p = .13$ (see Figure 4).

Figure 4

First-term Grade Point Average (GPA) ± SE for for Students Enrolled in First Term of Major's Biology during the 2014/15 Academic Year (N = 336)



Note. Categories were assigned based on transfer status achieved on or before fall 2020

Completed College Level Math First Year

Three of the seven variables examined as leading indicators of academic momentum were discrete categorical variables, including enrollment intensity in the first-year, completed college-level math in the first year, and completed the first class in the major's level biology sequence in the first year (see Table 7). The group of students who transferred into a professional program or into graduate school had the highest level of passing college level math in the first year (89%, $n = 9$), although there was no significant difference between the number of students who had completed college level math by their first year-for different transfer outcome categories ($\chi^2(3, N = 297) = 5.31, p = .15$).

Completed First Course in Major's Biology Sequence First Year

Additionally, there was no significant difference in the number of students who completed the first course in the biology major's sequence in their first year for different transfer outcome categories ($\chi^2(3, N = 336) = 2.03, p = .57$). Most students (80%, $n = 268$) in all categories did not complete the first course in the sequence in their first year. This finding reflects both a high failure rate and the fact that most students did not begin the major's biology sequence in their first year, even if they eventually transferred to a four-year school in a biology or biology-related program. Only 30% ($n = 102$) attempted the first course in the major's biology sequence in their first year of enrollment at the community college, with 67% (n = 68) of those students completing the course on the first attempt.

Enrollment Intensity First Year

There was also no significant difference in the patterns of enrollment intensity in the first year by transfer outcome category ($\chi^2(3, N = 336) = 7.12, p = .63$). The pattern of enrollment was consistent in all categories of transfer outcome with most students attending either full time or less than half time (see Table 7).

Table 7

Frequency of Students Enrolled in First Term of Major's Biology 2014/15 Academic Year in Categorical Leading Indicator Variables by Transfer Outcome Category as of Fall 2020 (N = 336)

	Transfer Outcome									
	No Transfer		Transfer Biology		Transfer Non Biology		Transfer Professional or Graduate School		Total	
Leading Indicators	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Completed college math first year										
No	41	50	56	47	44	51	1	11	142	48
Yes	41	50	63	53	43	49	8	89	155	52
Total	*82*		*119*		*87*		*9*		*297*	
Completed first course in major's biology sequence first year										
No	75	81	100	76	87	83	6	67	268	80
Yes	18	19	29	23	18	17	3	33	68	20
Total	*93*		*129*		*105*		*9*		*336*	
Enrollment Intensity First Year										
Less than half-time	27	29	42	33	38	36	3	33	110	33
Half-time	10	10	14	11	8	8	2	22	34	10
Three Quarter-time	15	16	14	11	19	18	2	22	50	15
Full-time	41	44	59	46	40	38	2	22	142	42
Total	*93*		*129*		*105*		*9*		*336*	

Predictive Value of Leading Indicators for Transfer Outcome

A logistic regression model (Hosmer et al., 2013) was constructed to examine the value of leading indicators identified for community college students in general, that predict successful transfer to a four-year institution, for the cohort of students taking the first course in the biology major's sequence in the 2014/15 academic year. The selection of variables to investigate was based on previous research (Adelman, 1999, 2005, 2006; Bailey et al., 2018; Belfield et al., 2019). These variables included: college-level credit accumulation in the first term and the first year, the completion of college-level math in the first year, first-term grade point average, completion of the first course in the major's biology sequence in the first year, accumulation of credits specific to the major's transfer map (MTM) (HECC, 2020) and enrollment intensity in the first year.

Purposeful selection (Bursac et al., 2008; Hosmer et al., 2013) was used to choose candidates as covariates to fit an initial multinomial logistic regression model. Screening for covariates was done using likelihood ratio tests from univariate logistic regression analyses with a conservative screening level of $p < .25$ (Mickey & Greenland, 1989). Using this method, the following variables were identified for the initial model: completion of college-level math in the first year, first-term grade point average, and accumulation of credits specific to the major's transfer map (MTM) (see Table 8). The likelihood ratio test was chosen as a screening tool instead of the Wald statistic because simulation studies have shown that it leads to fewer Type II errors when the sample size is small to moderate (Hosmer et al., 2013). Some data were missing for the variable completion of college-level math in the first year, so subsequent tests of the initial model were carried out using only participants whose information was complete for all three variables (*N* = 297).

Table 8

Leading Indicators of Academic Momentum Coded for Multinomial Logistic Regression Model

Leading Indicator	*N*	χ^2	*df*	*p*
College credits completed first term	336	.91	3	.82
College credits completed first year	336	.57	3	.90
GPA first term	336	10.14	3	.02*
Program credits completed first year	336	4.67	3	.20†
College math completed first year	297	6.05	3	.11†
First course major's biology completed first year	336	1.93	3	.59
Enrollment intensity first year	336	1.49	3	.68

Note.† $p < 0.25$, *$p < .05$.

No Transfer as reference category for logistic regression model

Building the Model

Using the variables identified through purposeful selection, the initial logistic regression model was run to determine the effects on the likelihood of being in one of the four transfer categories predicted by the following variables; completion of college-level math in the first year, first-term grade point average, and accumulation of credits specific to the biology major's transfer map (MTM). The reference category was set to be no transfer. The logistic regression model including these variables as predictors was significantly better at explaining the variance in the data than the baseline model with no predictors (χ^2 = 19.11(9), *p* = .024). The model correctly classified 40% of cases. Consistent with the covariates, including number of credits accumulated in a program specific to a biology transfer, the model correctly classified 98% of the cases transferring in a biology or biology-related discipline, but predicted membership in other categories poorly. Neither the Pearson (χ^2 = 368.83(477), p = 1.00) nor the Deviance (χ^2 = 373.34(477), p = 1.00) Goodness-of-fit were significant, indicating that there was no significant difference between the predicted and observed data, and the model was a good fit. These measures have been criticized as over-estimating the fit of the model when the covariates are continuous, so Python was used to compute a generalized Hosmer-Lemeshow goodness-of-fit test for multinomial logistic regression models (Fagerland & Hosmer, 2012). This test is slightly different than the Hosmer-Lemeshow test available for binary logistic regression in SPSS but can also be applied to binary logistic regression and will provide similar results (Fagerland & Hosmer, 2012). The generalized Hosmer-Lemeshow goodness-of-fit test was also not significant (χ^2 = 9.80(24), p > .99), confirming that the observed results were not significantly different than those predicted by the model.

The likelihood ratio tests for the contribution of each covariate as a predictor in the overall model indicated that GPA first term was a significant predictor (χ^2 = 9.20(3), p = .027), while completed college math first year (χ^2 = 5.63(3), p = .13) and accumulation of program credits in the MTM (χ^2 = 4.80(3), p = .19) were not significant predictors. A second more parsimonious model was fit by sequentially removing the non-significant predictors. Values of the estimated coefficients in the larger model were compared to those in the reduced models to determine if the variables being removed were effect modifiers. The removal of the non-significant predictors did result in a change in the estimated coefficient for first term GPA by more than 20%; therefore, the variables were added back into the model (Field, 2018; Hosmer et al., 2013), and the initial model was accepted as the main effects model (see Table 9). Checks for interactions between variables were carried out and none were found to contribute significantly to the main effects model. A review of the pseudo R^2 values suggested that although the model with predictors significantly explained more of the variance in the data, the effect size of the variables chosen as predictors was small (Cox & Snell = .06; Nagelkerke = .07).

Tests of Model Assumptions

Logistic regression models assume that the outcomes are not biased by collinearity between the independent variables, and that there is a linear relationship between the continuous variables and the logit of the dependent variable. Tests for multicollinearity were run to identify variables that had unacceptable levels of correlation and would violate the assumptions of the logistic regression model (Field, 2018). The variance proportions suggested some level of association between accumulations of program credits in the MTM and completing college math in the first year. This finding is not surprising since college math is one of the elements of the MTM, but none of the tolerance levels were less than .1 (Menard, 1995) and all variance inflation factor (VIF) values were below 2, indicating acceptable levels of correlation between the covariates (Myers, 1990).

Finally, a Box-Tidwell Test (Field, 2018) was used to confirm the linear relationship between the continuous independent variables and the natural log of the outcome variable (logit). The interactions between each continuous independent variable and its natural logarithm were not significant when added to the model, indicating that the assumptions of linearity were not violated for the variables included in the model.

Contributions of Predictors

The logistic regression model was significantly better at explaining the variance in the data-than the baseline model with no predictors (χ^2 = 19.11(9), p = .024). The predictor factors included: the effects of completion of college-level math in the first year, first-term grade point average, and accumulation of credits specific to the biology major's transfer map (MTM). Of those variables, only GPA first term was a significant predictor (χ^2 = 9.20(3), p = .027) for the overall model. The relationship of each variable to the different categories of transfer outcome was more complex, indicating that different variables contributed in different ways for each of the transfer outcome categories (see Table 9). Variables that were significant predictors of the category of transfer compared to no transfer were determined using the Wald statistic. Standard errors were rescaled for under dispersion using the Pearson statistic (Field, 2018).

Table 9

Multinomial Logistic Regression Model for Leading Indicators of Academic Momentum

Transfer Pathway	Indicator	*B*	*SE*	Wald	*df*	Sig.	Exp(*B*)	95% Confidence Interval for Exp(B)	
								Lower Bound	Upper Bound
Transfer to Biology or Biology-related Program	Intercept	.374	.314	1.416	1	.234			
	First term GPA	-.055	.099	.316	1	.574	.946	.780	1.148
	Program Credits Earned First Year	.027	.016	2.921	1	.087	1.027	.996	1.060
	Completed College Math First Year	-.232	.332	.490	1	.484	.793	.414	1.519
Transfer to a Non Biology-related Program	Intercept	-.056	.346	.026	1	.872			
	First term GPA	.045	.108	.177	1	.674	1.046	.847	1.293
	Program Credits Earned First Year	.001	.018	.006	1	.936	1.001	.968	1.036
	Completed College Math First Year	-.061	.349	.031	1	.861	.940	.474	1.866
Transfer to a Professional or Graduate Program	Intercept	-10.747	4.051	7.039	1	.008**			
	First term GPA	2.026	1.026	3.904	1	.048*	7.586	1.016	56.619
	Program Credits Earned First Year	-.034	.036	.894	1	.344	.966	.900	1.037
	Completed College Math First Year	2.155	1.035	4.334	1	.037*	8.630	1.134	65.651

Notes. $^{*}p < .05$, $^{**}p < .01$. No Transfer as reference category for logistic regression model.

Transfer to a Program that was Biology or Biology-related

None of the variables were significant ($p \geq .05$) predictors of transfer to a program that was biology or biology-related compared to not transferring at all (see Table 9). The trend in the estimated odds ratios suggested that as the number of credits earned in the biology MTM increased there was an increase in the odds of transferring into a biology or biology-related program. The estimated odds ratios also suggested that an increase in first-term GPA and completing college level math in the first year predicted a decrease in the odds of transferring into a biology related program compared to not transferring.

Transfer to a Program that was Non-biology Related

None of the variables were significant ($p \geq .05$) predictors of transfer to a program that was not biology or biology-related compared to not transferring at all (see Table 9). The trends in the estimated odds ratios suggested that as GPA and number of credits earned in the biology MTM increased, there was an increase in the odds of transferring. The estimated odds ratios also suggested that completing college-level math in the first-year decrease in the odds of transferring into a program that was not biology compared to not transferring.

Transfer to a Professional or Graduate Program

First term GPA was a significant predictor ($B = 2.03$, ($SE = 1.03$) Wald = 3.90, $p = .048$) for transferring to a graduate or professional program compared to not transferring to a four-year institution. The estimated odds ratio (Exp(B) = 7.57) indicated that for every one-point increase in first-term GPA, the odds were 7.57 times higher of transferring in this category compared to not transferring. The strong association between GPA and successful transfer to a professional or graduate program may reflect the competitive nature of programs such as pharmacy, that students transferred into. These data would not reflect unsuccessful applications to professional programs. Completing college math in the first year was also a significant predictor (*B*= 2.15, (*SE* = 1.03) Wald = 4.33, $p = .037$) for transferring into a graduate or professional program. The estimated odds ratio (Exp(*B*) = 8.63) indicated that completing college math resulted in the odds being 8.63 higher of transferring into a professional or graduate program. Accumulating program credits associated with the biology major's transfer map (MTM) was not a significant predictor ($p \geq .05$) variable for students transferring to a professional or graduate program. The odds ratio less than one suggests that for every one-credit increase in classes associated with the biology MTM, the student was less likely to transfer into a professional or graduate program (see Table 9). This is intuitive if the student's goal was not to transfer into a biology program but to acquire prerequisite classes that happened to overlap. All the students in this category transferred to programs in health professions and related clinical sciences.

Research Question Two

The second research question was: What is the pattern of course-taking behavior of students in a biology-degree transfer sequence at a large western community college?

The course-taking patterns of the group of students, 18 years or older, who were enrolled in the first term of the major's biology sequence class were examined. Aspects of course-taking examined included the level of biology, chemistry, physics, and math taken prior to enrollment in the first class in the major's biology sequence, grade outcome, retention through the three-term sequence of major's biology, continuity of course-taking for sequential classes and enrollment intensity. These patterns of course-taking only reflect courses on the community college transcript and do not include experiences students may have had in high school with International Baccalaureate (IB) or Advanced Placement (AP) classes. Students planning to transfer to a biology or biology-related program at a four-year institution would need to take a suite of STEM courses, including biology, chemistry, physics, and math. The timing for some of the course-taking would be driven by pre-requisites but in the cafeteria model of course-taking available to students during the 2014/15 academic year, students could enter the major's biology sequence at different times in their community college career having taken a variety of other STEM courses.

Prior Biology Coursework

The level of college coursework taken by students prior to their first attempt of the first course in the major's biology sequence varied by the number and the level of coursework (see Table 10). Analysis of the data showed that 63% (n = 214) of students had no record of any college-level biology coursework prior to attempting major's biology, while 37% (n = 85) had a mix of 100 and/or 200 level coursework already on their transcripts. The number of prior biology classes ranged widely from zero to seven with 37% of students (n = 128) having some prior college-level biology on their transcript. Table 10 contains a breakdown of the prior biology course-taking behavior by level.

Table 10

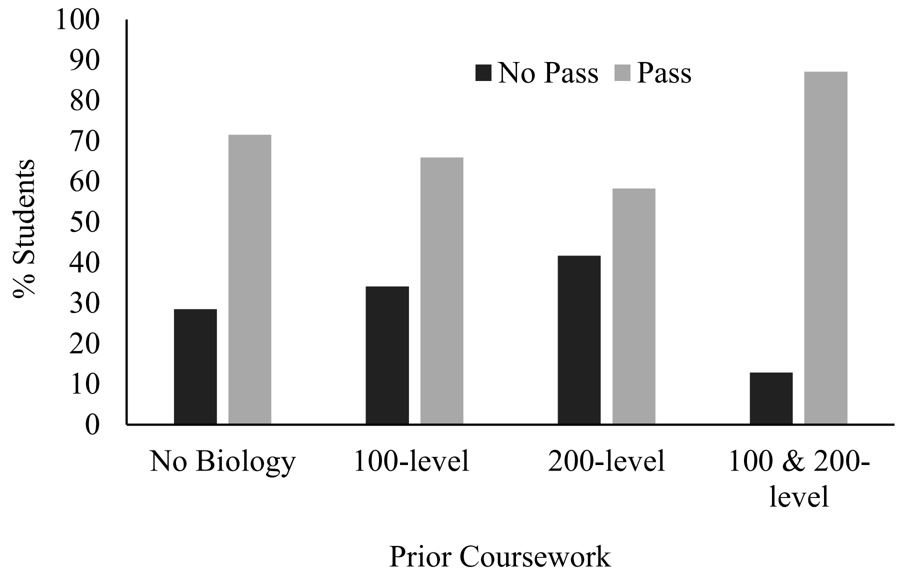
Number of Students Entering First Term of Major's Biology Sequence with Prior Coursework in Biology (N = 342)

Category of Biology Taken	*n*	%
No biology	214	63
100-level biology	85	25
200-level biology	12	4
100 & 200-level biology	31	9

Students had completed an average of 3.37 credits (*SD* = 5.63) of biology prior to entry, with a range of 0 to 30 credits. Students were categorized based on the records in their transcript of prior college-level biology course-taking behavior. The categories included: (a) no prior biology, (b) 100 level courses in biology, (c) 200 level courses in biology, and (d) both 100 and 200 level courses in biology. There was no significant difference in the number of students who completed the first-term of the major's biology sequence on their first attempt based on their category of prior biology course-taking behavior ($\chi^2(3, N = 342) = 5.95, p = .11$) (see Figure 5). However, students who were in different course taking categories did receive significantly different grades in the first term of the major's biology sequence ($\chi^2(9, N = 342) = 19.19, p = .03$). The effect size for prior biology course-taking was modest (*phi* = .23).

Figure 5

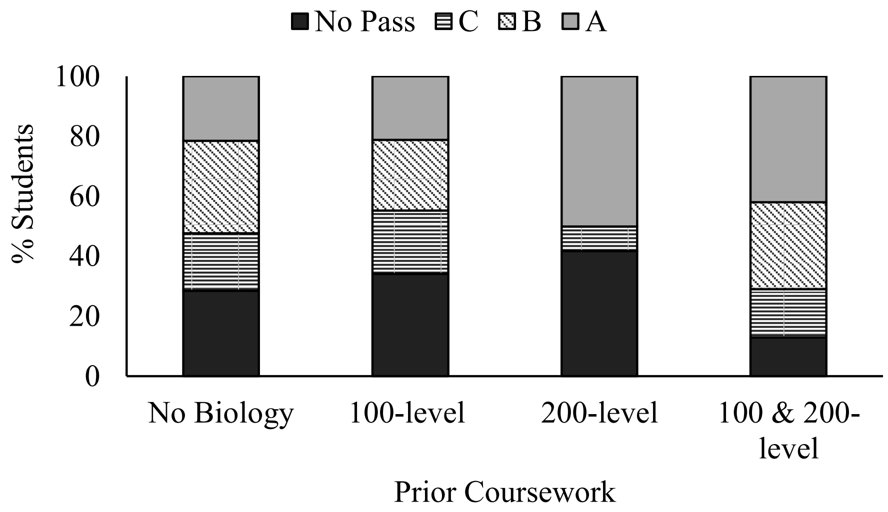
Completion of Major's Biology and Level of Coursework in Biology Prior to Enrollment (N = 342)



Students who had successfully completed other 200 level biology prior to attempting the major's biology sequence tended to receive higher grades, while this was not necessarily the case for students who had successfully taken 100-level biology classes prior to attempting the major's biology sequence (see Figure 6).

Figure 6

Grade Distribution and Level of Prior Coursework in Biology Prior to Enrollment in Major's Biology (N = 342)



Prior Chemistry Coursework

Chemistry is a required co-requisite for the first class in the major's biology sequence. Data analysis indicated that 43% (n = 148) of the students had no record of attempting any college-level chemistry coursework on their transcripts prior to attempting major's biology, but 57% (n = 194) had a mix of 100 and 200 level coursework (see Table 11).

Table 11

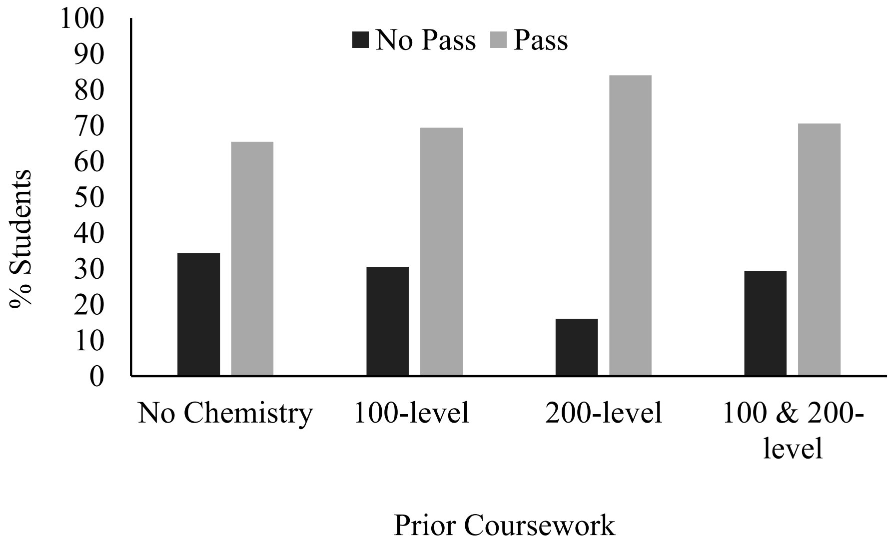
Number of Students Entering First Term of Major's Biology Sequence with Prior Coursework in Chemistry (N = 342)

Category of Chemistry Taken	*n*	%
No chemistry	148	43
100-level chemistry	85	25
200-level chemistry	75	22
100 & 200-level chemistry	34	10

Students had completed an average of 5.0 credits (*SD* = 5.79) of chemistry prior to entry, with a range of 0 to 30 credits. Students were categorized based on the records in their transcript of prior college-level chemistry course-taking behavior. The categories included: (a) no prior chemistry, (b) 100 level courses in chemistry, (c) 200 level courses in chemistry, and (d) both 100 and 200 level courses in chemistry. There was a significant difference in the number of students who completed the first course in the major's biology sequence on their first attempt based on their category of prior chemistry course-taking behavior ($\chi^2(3, N = 342) = 8.41, p = .04$), with a modest effect size (*phi* = .16) (see Figure 7).

Figure 7

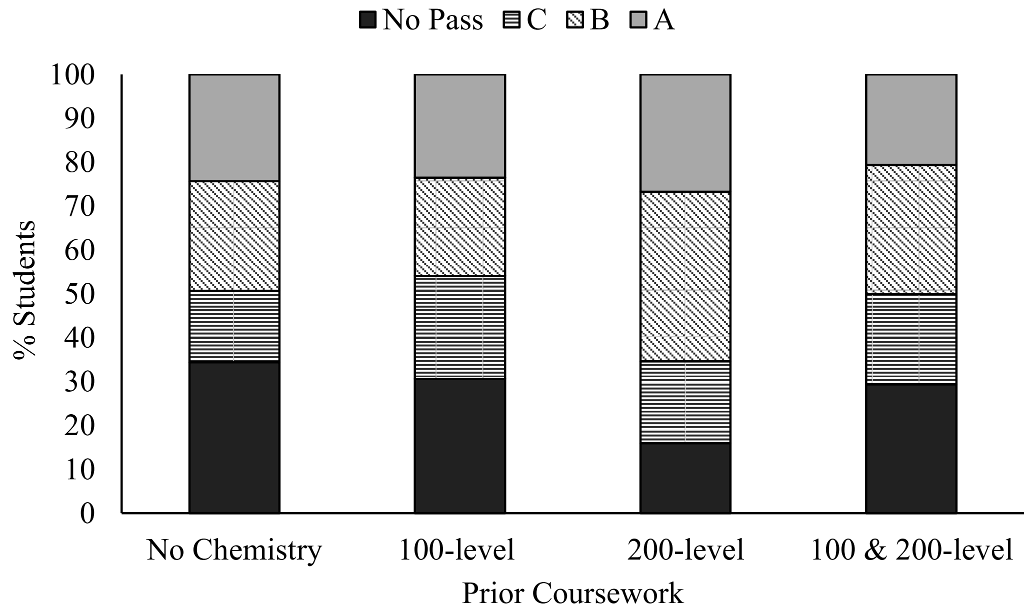
Completion of First Course in Major's Biology and Level of Coursework in Chemistry Prior to Enrollment (N = 342)



However, unlike the relationship between prior course taking in biology and grades, students who were in different course taking chemistry categories did not receive significantly different grades in the first course in the major's biology sequence (χ^2(9, N = 342) = 12.48, p = .19) (see Figure 8).

Figure 8

Grade Distribution and Level of Prior Coursework in Chemistry Prior to Enrollment in Major's Biology (N = 342)



Prior Physics Coursework

Next, the data were analyzed to determine prior coursework in physics. Fewer students attempting the first class in the major's biology sequence for the first time had prior college physics coursework compared to their history with biology and chemistry. Findings indicate that 88% (*n* = 302) of the students had no record of attempting any college-level physics coursework prior to attempting major's biology with a few students with 100-level (3%, *n* = 9) and 200-level physics (9%, *n* = 31). None of the students in the sample had both 100- and 200-level physics prior to taking the first class in the major's biology sequence (see Table 12).

Table 12

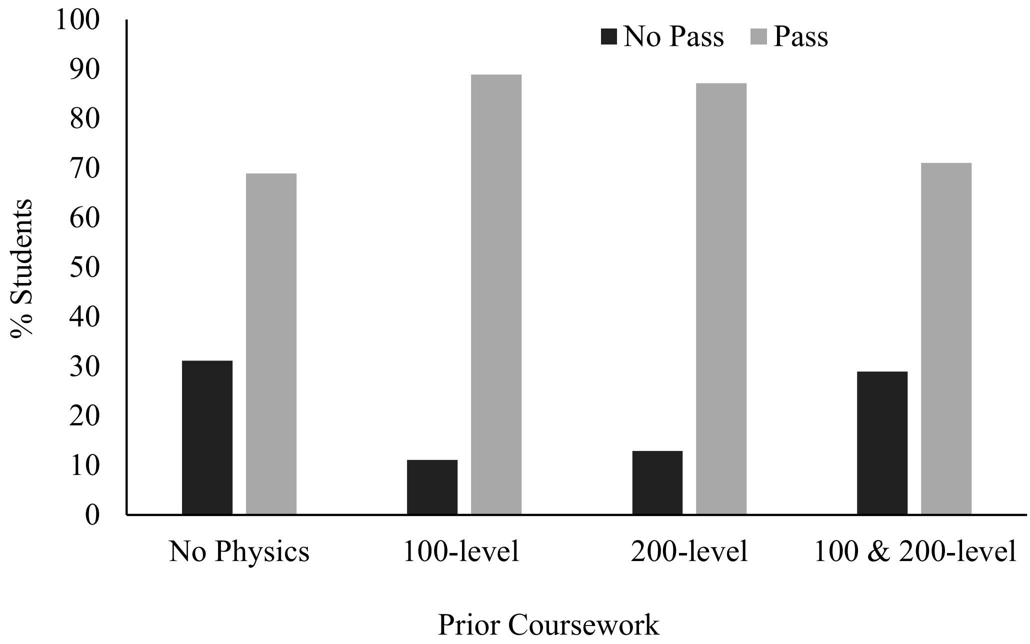
Number of Students Entering First Term of Major's Biology Sequence with Prior Coursework in Physics (N = 342)

Category of Physics Taken	*n*	%
No physics	302	88
100-level physics	9	3
200-level physics	31	9

Additionally, students had completed an average of .77 credits (*SD* = 2.52) of physics prior to entry, with a range of 0 to 15 credits. The range of physics courses taken by any one student was zero to five. Students were categorized based on the records in their transcript of prior college-level physics course-taking behavior. The categories included: (a) no prior physics, (b) 100 level courses in physics, and (c) 200 level courses in physics. There was no significant difference in the number of students who completed the first-term of the major's biology sequence on their first attempt based on their category of prior physics course-taking behavior ($\chi^2(2, N = 342) = 5.97$, $p = .051$) (see Figure 9). The trend suggested that with a larger sample size this may have been a significant effect.

Figure 9

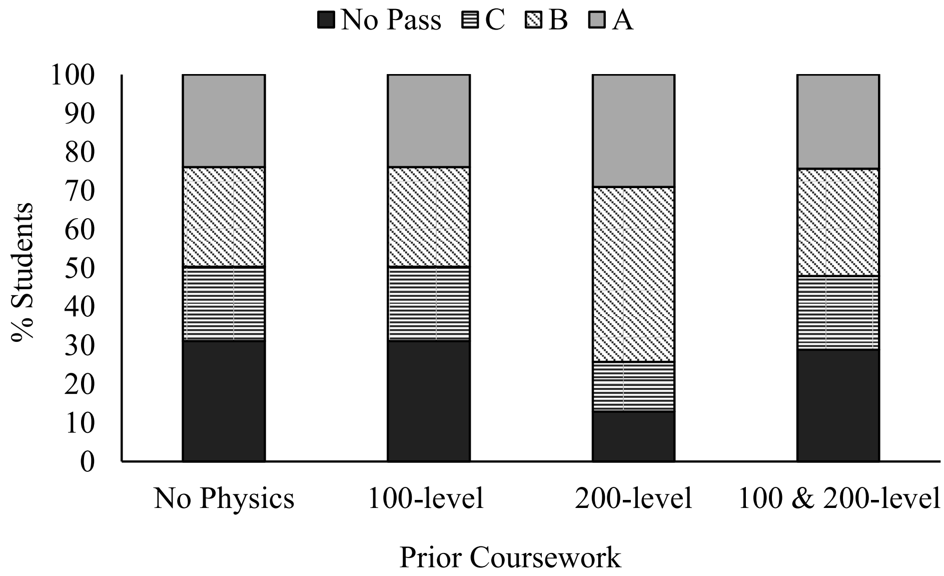
Completion of Major's Biology and Level of Coursework in Physics Prior to Enrollment (N = 342)



Students who were in different course taking physics categories also did not receive significantly different grades in the first course in the major's biology sequence ($\chi^2(6, N = 342) = 10.04$, $p = .12$) (see Figure 10).

Figure 10

Grade Distribution and Level of Prior Coursework in Physics Prior to Enrollment in Major's Biology (N = 342)



Prior Math Coursework

Assessing the prior course-work in math for students attempting the first course in the major's level biology sequence was more complex than for biology, chemistry or physics because students had more options for pathways. In addition to 100- and 200-level college courses students might also be taking pre-college remedial math courses. The math prerequisite for the major's biology sequence was completion of intermediate algebra, a pre-college level math class. Completion of this math class would also fulfill the prerequisites for entry into the 100-level or college math classes. Students could meet this prerequisite by taking the appropriate remedial math classes, testing into a higher-level math class, or transferring in the appropriate math coursework. This fact is important because the absence of math coursework on the transcript should be interpreted cautiously. The earlier examination of the relationship between completing college level math in the first year and transfer used additional course-taking behavior, such as enrolling in a class with a math prerequisite, to assess math background, but these analyses are based solely on the math courses in the student's community college transcript, therefore the category 'no math' does not mean no math background, just no math courses taken at the community college in the study. Most students (67%, *n* = 231) had some level of math coursework on their transcript prior to taking major's level biology, with seven possible combinations (see Table 13).

Table 13

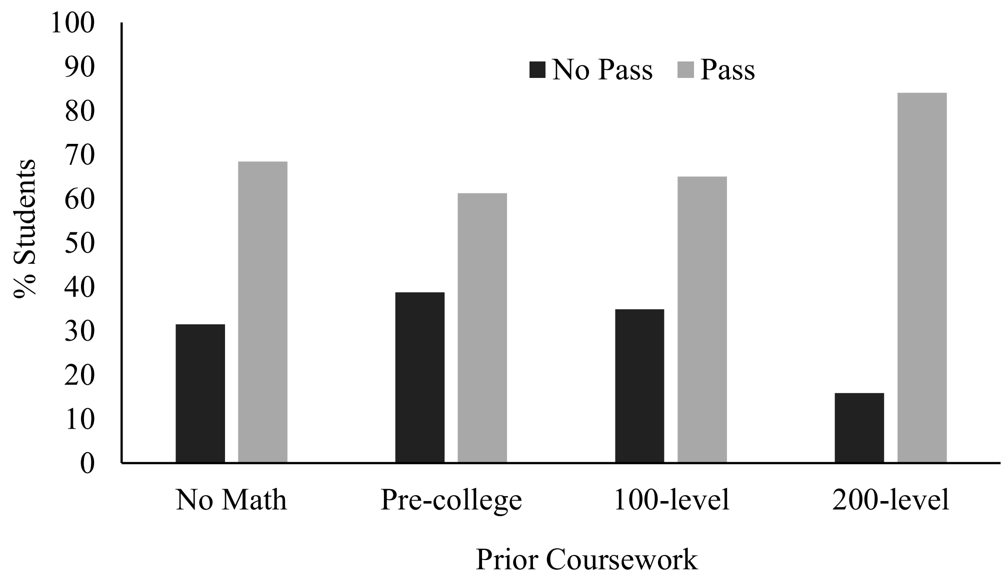
Number of Students Entering First Term of Major's Biology Sequence with Prior Coursework in Math (N = 342)

Category of Math Taken	*n*	%
No math on transcript	111	33
Pre-college math	31	9
100-level math	36	10
200-level math	25	7
Pre-college & 100-level math	70	20
100 & 200-level math	27	8
Pre-college,100 & 200-level math	41	12
Pre-college & 200-level math	<5	<1

Students had completed an average of 5.65 credits (*SD* = 6.12) of math at the community college prior to attempting the first course in the major's biology sequence, with a range of 0 to 28 credits. The most frequent pattern of coursework taken was a combination of pre-college and 100-level math courses (20%, *n* = 70). Due to the large number of categories and a relatively small sample size, categories were collapsed to reflect the highest level of math taken. The categories for analysis included: (a) no math, (b) remedial math, (c) 100-level math, and (d) 200-level math (see Figure 11). There was a significant difference in the number of students who completed the first-term of the major's biology sequence on their first attempt based on the highest-level of prior math recorded on their transcript ($\chi^2(3, N = 342) = 11.34$, $p = .01$) with a modest effect size (*phi* = .18) (Muijs, 2016).

Figure 11

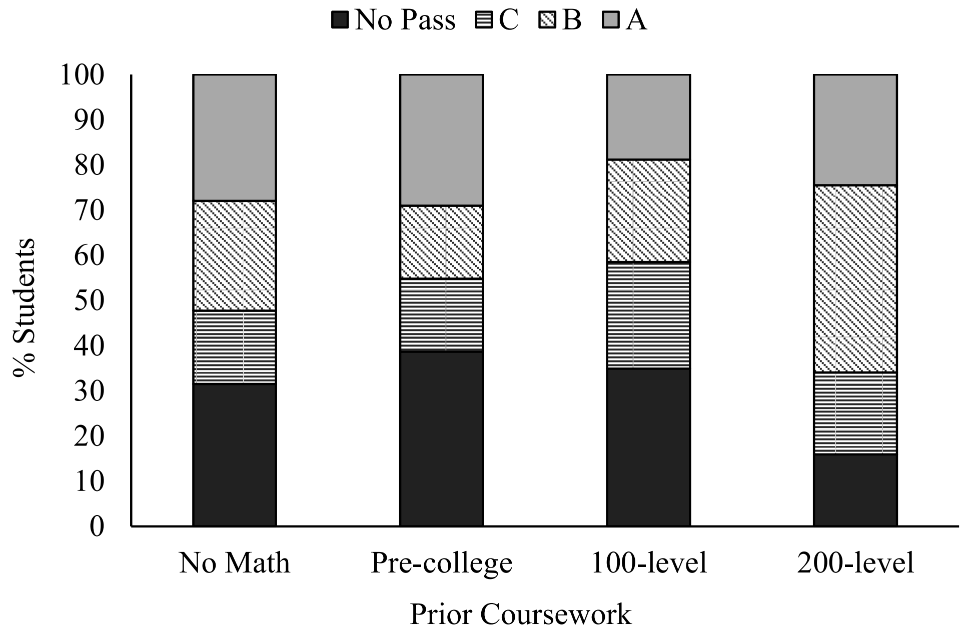
Completion of Major's Biology and Level of Coursework in Math Prior to Enrollment (N = 342)



Additionally, students with different levels of math also had significantly different grades in the first course in the major's biology sequence ($\chi^2(9, N = 342) = 21.39$, $p = .01$) (see Figure 12) with a modest effect size (*phi* = .25) (Muijs, 2016).

Figure 12

Grade Distribution and Level of Prior Coursework in Math Prior to Enrollment in Major's Biology (N = 342)



Grade Distribution

Analysis of the grade distributions indicated that the majority of students (71%, n = 243) completed the first class in the major's biology sequence with a C grade or higher (includes P) on the first attempt, with 29% (n = 99) of the students receiving a D, F, W, NP or I grade (see Table 14). For the students who were enrolled in the first term of the major's biology sequence class tracked, 17% would attempt the class more than once. A small number of students took the course four times (see Table 14). Of the 56 students who retook the class, 20% (n = 11) had already received a passing grade on the first attempt.

Table 14

Progression through the Major's Biology Sequence for Students the Enrolled in First Course in 2014/15 Academic Year (N = 342)

	Progression of Enrollment					
	First Course in Sequence		Second Course in Sequence		Third Course in Sequence	
Number of Attempts	*n*	%	*n*	%	*n*	%
Not enrolled			114	33	59	26
1	286	84	206	60	164	72
2	46	13	21	6	5	2
3 or more	10	3	<5	<1		
Grade First Attempt[a]						
A	83	24	63	28	57	34
B	95	28	77	34	65	38
C or P	65	19	47	21	38	22
D, F, W, NP, or I	99	29	41	18	9	5

Notes. P = pass, NP = no pass, I = incomplete;

[a]% grade received reflects only those students who attempted course

Retention in Major's Biology Sequence

The progression of the initial group of students identified for the study from the first term of the major's biology sequence through the second and the third terms of the three-course sequence was also tracked. The level of attrition from the first to the second (33%, *n* = 114) and from the second to the third class (26%, *n* = 59) remained relatively consistent with 49% (*n* = 169) of the initial group of students progressing through all three terms of the sequence. These numbers reflect the progression of students who passed the prerequisite course in the sequence on the first attempt and those who repeated the prerequisite. The first course in the major's biology sequence was repeated by 17% (*n* = 56) of the students who, with a small number repeating it three or more times (3%, *n* = 10). Some of the students repeating the class (20%, *n* = 11) had received a passing grade the first time. All those students progressed to the second course in the sequence, although only 64% (*n* =7) received a higher grade the second time. Only 60% of the 45 students who repeated the first class because of non-completion eventually progressed to the second course in the sequence. It is important to note that the proportion of students completing the major's biology classes increased in the second course in the sequence and again in the third (see Table 14). Some students completed the pre-requisite class but chose not to continue. Of the students who completed the first course in the major's biology sequence 18% (*n* = 44) did not enroll in the second course. A similar proportion of the students who completed the second course in the major's biology sequence (18%, *n* = 34) did not enroll in the third course. This pattern suggests that they did not require the class for their educational goals or that factors other than grades impacted their retention in the sequence.

Continuity

Most (82% or more) who completed a course in the major's biology sequence on the first attempt enrolled in the next course in the sequence in the next term (see Table 15). Only 4% (*n* = 8) of students who completed the pre-requisite class on the first attempt waited more than a year (five terms or more) to take the next class. The variation within the latter small number of number of students was very broad, with a range of 16 terms between classes. Students who did not pass on the first attempt had a broader gap, up to 81 terms, but if this was adjusted to account for the gap between the next attempt in the first course major's biology and the next class in the sequence, the range did not differ between groups.

Table 15

Number of Terms Between Enrollment in Sequence of Major's Biology Courses for Students Completing Prerequisite Course on First Attempt

	Sequence of Enrollment			
Terms	First Course to Second Course	%	Second Course to Third Course	%
≤1	164	82	121	86
2	18	9	8	6
3	6	3	3	2
4	3	1	5	3
≥5	8	4	5	3
N	199		140	

Notes. A sequence of enrollment <1 represents concurrent enrollment or enrollment prior.

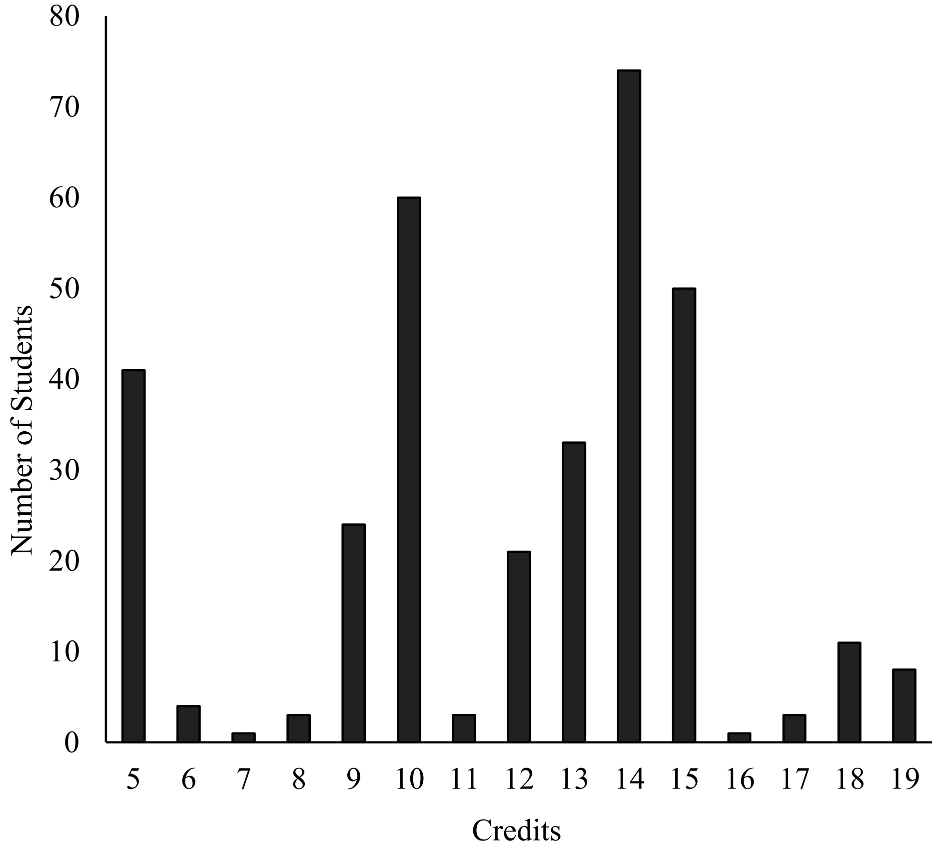
% may not add up to 100 due to rounding.

Enrollment Intensity

The total number of credits a student is enrolled in during a given term is a measure of enrollment intensity. The number of credits the students enrolled in the first term of the major's biology sequence during the 2014/15 academic year were carrying the first time they took the class varied greatly ($M = 11.83$, $SD = 3.57$). The first term of the major's biology sequence was a five-credit class so 41 students were just taking the major's biology class, while most were carrying close to a full load of 12 credits or more (see Figure 13).

Figure 13

Enrollment Intensity During First Attempt First Course in Major's Biology Sequence (N = 342)



Research Question Three

The third research question was: What is the pattern of course-taking behavior in a biology-degree transfer sequence for students disaggregated by gender, age, race, and ethnicity at a large community college in the west?

Prior Coursework in Biology, Chemistry, Physics and Math Disaggregated by Gender

Student course-taking behaviors were disaggregated by gender using the binary categories of male and female. Not all students identified as male or female, but to maintain confidentiality, students who did not report were not included in the disaggregated data. Based on the binary classification of gender, there were no significant differences in the level of biology coursework completed prior to enrolling in the first term of the major's biology sequence ($\chi^2(3, N = 337) = .56, p = .91$). Most female students (62%, $n = 123$) had no prior college-level biology coursework on their transcripts. Most male students (64%, $n = 88$) also had no prior college-level biology coursework on their transcripts (see Table 16). There was also no significant difference in the level of chemistry coursework completed prior to enrolling in the first term of the major's biology sequence between male and female students ($\chi^2(3, N = 337) = .93, p = .82$). Most female students (58%, $n = 117$) had some prior college-level chemistry coursework on their transcripts. Similarly, most male students (55%, $n = 75$) also had some college-level chemistry coursework on their transcripts (see Table 16). Consistent with the patterns observed for biology and chemistry course-taking there were no significant differences between female and male students observed in the level of physics coursework completed prior to enrolling in the first term of the major's biology sequence ($\chi^2(2, N = 337) = 1.01, p = .60$). Most female students (89%, $n = 178$) and most male students (87%, $n = 119$) had no college-level physics on their transcripts (see Table 16). This contrasts with the patterns for math course taking where both female (53%, *n* =123) and male (67%, *n* = 92) students, had some college-level math on their transcripts (see Table 16). There were no significant differences in the level of prior math on the student's transcript prior to enrolling in the first term of the major's biology sequence ($\chi^2(2, N = 228) = .35, p = .84$). It is important to note that the first course in the major's biology sequence has a precollege level math pre-requisite and 109 students in the sample had no record of math taking on their community college transcript and are not represented in the disaggregated Chi-square data analysis. Given the available data it was not possible to determine if these students had tested out of the precollege math prerequisite, transferred in credit, or had the math prerequisite waived.

Table 16

Students Entering the First Term of the Major's Biology Sequence with Prior STEM College Coursework Disaggregated by Gender (N = 337[a])

		Gender			
		Female		Male	
	Prior Coursework	*n*	%	*n*	%
Biology	No biology	123	62	88	64
	100-level biology	50	25	34	25
	200-level biology	8	4	4	3
	100 & 200-level biology	19	9	11	8
Chemistry	No chemistry	83	41	62	45
	100-level chemistry	52	26	31	23
	200-level chemistry	46	23	29	21
	100 & 200-level chemistry	19	9	15	11
Physics	No physics	178	89	119	87
	100-level physics	6	3	3	2
	200-level physics	16	8	15	11
Math[b]	No math on transcript	77	38	32	23
	Pre-college math	16	8	13	9
	100-level math	59	29	47	34
	200-level math	48	24	45	33

Notes. [a]A students who did not identify as male or female, removed to retain confidentiality.

[b]Represents the highest level on transcript.

Grade Distributions in Major's Biology Sequence Disaggregated by Gender

Examination of the grade distributions disaggregated by gender indicated similar patterns of achievement on the first attempt for all three courses in the major's biology sequence (see Table 17). There were no significant differences between female and male students in the grade distributions for the first course of major's biology ($\chi^2(3, N = 337) = 2.29, p = .51$). The number of student's passing the first class in the major's biology sequence with a C or better on the first attempt was similar for female (71%, $n = 143$) and male (70%, $n = 96$) students. This was also the case for the second course in the major's biology sequence, where 83% (*n* = 114) of the female and 81% (*n* = 71) of the male students completed with a C or better on the first attempt. There were no significant differences between female and male students in the grade distributions for the second course of major's biology ($\chi^2(3, N = 225) = 1.09, p = .78$). The trend towards increasing completion rates for both groups continued in the third course in the major's biology sequence with 96% (*n* = 91) of the female students and 93% (*n* = 67) of the male students passing with a C or better on the first attempt. There were no significant differences between female and male students in the grade distributions for the third course of major's biology ($\chi^2(3, N = 167) = 1.73, p = .63$).

Table 17

Grade Distribution for Students Progressing through the Major's Biology Sequence Disaggregated by Gender (N = 337)

		Gender			
		Female		Male	
Grade[a]		*n*	%	*n*	%
First Course in Sequence	A	55	28	28	20
	B	53	26	40	29
	C or P	35	17	28	20
	D,F,W,NP or I	57	29	41	30
Second Course in Sequence	A	36	26	27	31
	B	48	35	28	32
	C or P	30	22	16	18
	D,F,W,NP or I	23	17	17	19
Third Course in Sequence	A	36	38	21	29
	B	35	37	29	40
	C or P	20	21	17	24
	D,F,W,NP or I	4	4	5	7

Notes. P = pass, NP = no pass, I = incomplete,

[a]% grade received reflects only those students who attempted course.

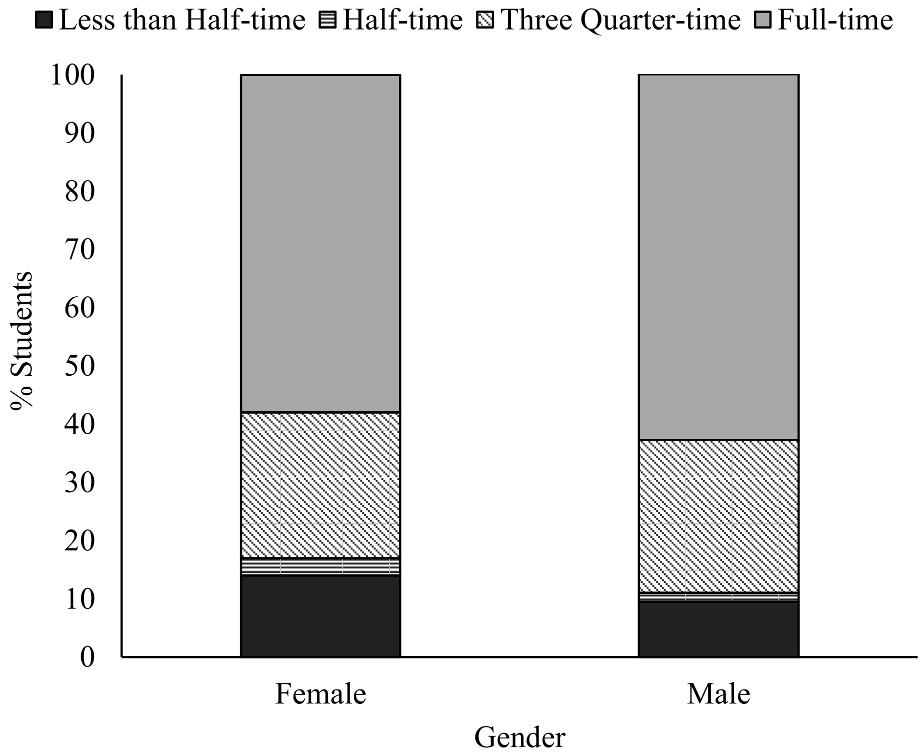
Enrollment Intensity Disaggregated by Gender

Enrollment intensity in the term the student first attempted the first course in the major's biology sequence was compared between females and males. Enrollment intensity was examined using both the total number of credits and the category of enrollment relevant for guidelines related to financial aid. These categories were: (a) Full-time was 12 or more credits, (b) Three quarter-time was 9 to 11 credits, (c) half-time was 6 to 10 credits, and (d) less than half-time was less than 6 credits. The first class in the major's biology class was 5 credits, so a student carrying just that one class would be less than half-time.

There was a wide range in the number of credits the students were enrolled in during the first-term of the major's biology sequence during the 2014/15 academic year (5 credits to 19 credits), with female students showing a lower enrollment intensity (M = 11.52, SD = 3.55) compared to males (M = 12.32, SD = 3.62). Fewer females (57%) compared to males (63%) were attending full-time (see Figure 14). More females (14%) than males (9%) were attending less than half-time, meaning the only course they were taking was the major's biology. A comparison of the enrollment intensity during the term the student was enrolled in the first course in the major's biology sequence for the first time indicated a significant difference between female and male students when compared using the t-test for independent samples ($t(335) = -2.01$, $p = .04$). The effect of gender on enrollment intensity was weak (*eta-squared* = .01) (Muijs, 2016).

Figure 14

Enrollment Intensity During First Attempt at Major's Biology Sequence Disaggregated by Gender (N = 337)



Prior Coursework Biology, Chemistry, Physics and Math, Disaggregated by Age

Student course-taking behaviors were disaggregated by age (see Table 18). Age categories represented traditional-age college students who are those 23 years and younger, as well as two categories of post-traditional age students; 24 to 29 years and 30 years and older. There were significant differences in the level of biology coursework completed prior to enrolling in the first term of the major's biology sequence ($\chi^2(6, N = 342) = 21.48, p = .002$) based on student age category. The effect size was modest (*phi* = .25) (Muijs, 2016). More post-traditional age college students had taken biology courses prior to enrolling in the first course in the major's biology sequence compared to traditional age students (see Table 18). There were also significant differences in the level of chemistry coursework completed prior to enrolling in the first term of the major's biology sequence ($\chi^2(6, N = 342) = 20.34, p = .002$) based on student age category. The effect size was modest (*phi* = .24) (Muijs, 2016). More post-traditional students 30 years and older had taken 100-level chemistry coursework compared to students in the other age categories. However, more traditional-age students had taken 200-level chemistry coursework compared to the post-traditional age students (see Table 18). Few students in any of the age categories had any physics coursework prior to enrolling in the first term of the major's biology sequence. There were no significant differences in the level of physics coursework completed prior to enrolling in the first term of the major's biology sequence ($\chi^2(4, N = 342) = 1.15, p = .87$) based on student age category. Similar to patterns for biology and chemistry, there were significant differences in the level of math coursework recorded on the transcript prior to enrolling in the first term of the major's biology sequence based on student age category. The effect size was modest (*phi* = .27) (Muijs, 2016).

Table 18

Number of Students Entering First Term of Major's Biology Sequence with Prior STEM College Coursework Disaggregated by Age (N = 342)

Prior Coursework		Age					
		≤23 years		24-29 years		≥30 years	
		n	%	*n*	%	*n*	%
Biology*	No biology	115	72	52	52	47	57
	100-level biology	37	23	28	28	20	24
	200-level biology	<5	<1%	6	6	5	6
	100 & 200-level biology	6	4	14	14	11	13
Chemistry*	No chemistry	71	45	44	44	33	40
	100-level chemistry	41	26	19	19	25	30
	200-level chemistry	42	26	19	19	14	17
	100 & 200-level chemistry	5	3	18	18	11	13
Physics	No physics	141	89	87	87	74	89
	100-level physics	3	2	3	3	3	4
	200-level physics	15	9	10	10	6	7
Math*[a]	Pre-college math	10	10	9	13	12	20
	100-level math	50	48	21	31	35	58
	200-level math	44	42	37	55	13	22

Note. [a]Highest level math course on community college transcript.

*$p < .05$, significant differences in the level of coursework prior to enrolling in the first term of the major's biology sequence

Grade Distributions in Major's Biology Sequence Disaggregated by Age

Examination of the grade distributions disaggregated by age indicated different patterns of achievement on the first attempt for all three courses in the major's biology sequence (see Table 19). Students in the youngest age category completed the first course in the major's biology sequence on the first attempt at a higher level (75%) than students who were 24 to 29 years old (68%) or students who were 30 and older (33%). A higher percentage of students who were 24 to 29 year's old received an A (31%) compared to other age groups. Grade distributions between age groups for the first course in the major's biology sequence were not significantly different ($\chi^2(6, N = 342) = 8.67, p = .19$). Completion rates increased for students attempting the second course in the major's biology sequence for the first time but not equally for all age categories (see Table 19). Students who were 23 years or younger completed the second course in the major's biology sequence (82%) at slightly lower rates than students in the next age category (87%) but at higher rates than students in the oldest age group (74%). The trend for a higher percentage of students who were 24 to 29 years old to receive an A (43%) continued in the second course of the major's biology sequence. Grade distributions between age groups for the second course in the major's biology sequence were significantly different ($\chi^2(6, N = 228) = 14.01, p = .03$) with a modest effect size (*phi* = .25) (Muijs, 2016). The achievement gaps between age groups narrowed and a trend towards increasing completion rates for all three age groups continued for the third course in the major's biology sequence with 94% of the students 23 years and younger passing the class on the first attempt, and 98% of the students 24 to 29 years passing on the first attempt and finally 92% of the students 30 years and older also passing the third class in the major's biology sequence on the first attempt. The observed trend that students who were 24 to 29 years old received A letter grades at a higher levels compared to other age groups continued in the third course in the major's biology sequence (see Table 19). However, grade distributions between age groups for the third course in the major's biology sequence were not significantly different ($\chi^2(6, N = 169) = 4.3, p = .64$).

Table 19

Grade Distribution for Students Progressing through the Major's Biology Sequence Disaggregated by Age (N = 342)

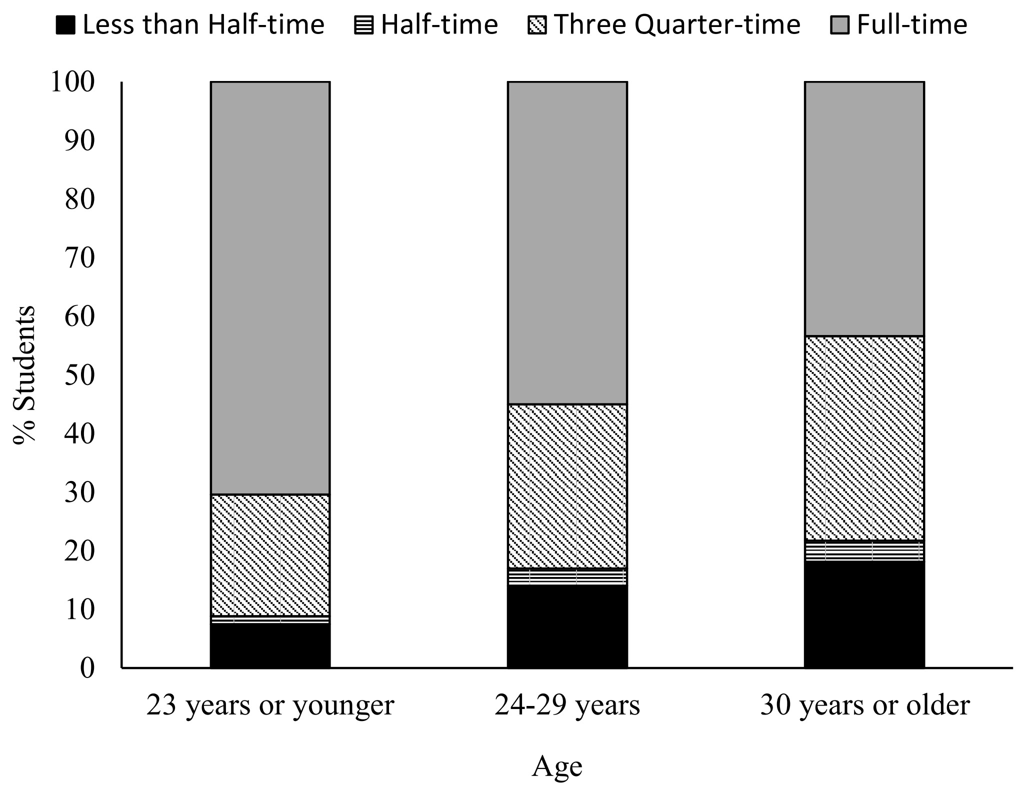
		Age					
		≤23 years		24-29 years		≥30 years	
Grade		*n*	%	*n*	%	*n*	%
First Course in Sequence	A	36	23	31	31	16	19
	B	52	33	22	22	21	25
	C or P	31	19	15	15	19	23
	D,F,W,NP or I	40	25	32	32	27	33
Second Course in Sequence	A	22	21	29	43	12	22
	B	39	37	19	28	19	35
	C or P	27	25	11	16	9	17
	D,F,W,NP or I	18	17	9	13	14	26
Third Course in Sequence	A	23	28	20	42	14	37
	B	34	41	17	35	14	37
	C or P	21	25	10	21	7	18
	D,F,W,NP or I	5	6	<5	<2	3	8

Enrollment Intensity Disaggregated by Age

There was a wide range in the number of credits the students were enrolled in the first-term of the major's biology sequence during the 2014/15 academic year with the youngest group of students showing the highest enrollment intensity (*M* = 12.72, *SD* = 3.41). The students in the next age group (24 to 29 years) had a slightly lower enrollment intensity (*M* = 11.27, *SD* = 3.45) and the older group of students had the lowest enrollment intensity (*M* = 10.80, *SD* = 3.65). Age categories were compared using a one-way ANOVA. There was a significant difference in the enrollment intensity during the term the student was first enrolled in the first course in the major's biology sequence between age groups ($F(2, 339) = 10.19$, $p < .001$). The effect size for age was weak (*eta-squared* = .06) (Muijs, 2016). Most students who were 23 years or younger (71%, $n = 111$) and just over half of the students who were 24 to 29 years (55%, $n = 54$) were enrolled full-time. Less than half (43%, $n = 36$) of the students who were 30 years or older were enrolled full time (see Figure 15). In the group of students who were 30 years or older and attending at less than half time (usually taking just one course), most of those students were female (87%, $n = 13$). This is not the case for the traditional age category of students where most of the females are attending full time and they constituted 61% ($n = 68$) of the full-time enrollment category.

Figure 15

Enrollment Intensity During First Attempt at Major's Biology Sequence Disaggregated by Age (N = 342)



Prior Coursework in Biology, Chemistry, Physics and Math Disaggregated by Race and Ethnicity

Student course-taking behaviors were disaggregated by race and ethnicity, using self-reported categories of identity. The representation in some of the categories was low, and so to preserve student confidentiality, data were aggregated for categories where the initial sample was less than 10 cases. The category designated American Indian and Other Races/Ethnicities represents students who identified as American Indian, Hawaiian/Pacific Islander or non-resident alien. To further ensure confidentiality, levels of course taking prior to enrollment in the first course of the major's sequence were collapsed to represent the highest levels or course taking. The number of categories in relationship to the sample size precluded using inferential statistics for some comparisons. A description of the emerging trends from descriptive statistics informs the question of what the patterns of course-taking behavior were for students identifying in different racial and ethnic groups.

Most White, Asian, and Hispanic students entered the first course in the major's biology sequence with no prior college-level biology coursework on their transcript (see Figure 16). This trend was also true for students who did not choose to report their race and ethnicity and American Indian, Hawaiian/Pacific Islander and non-resident alien students who are represented in the American Indian and Other Races/Ethnicities category. Half of the multiracial students (50%) entered the major's biology sequence with some prior college level biology experience, mostly (37%) with 100-level biology courses. In contrast, most of the Black/African American students entered the first course in the major's biology sequence with some prior college level biology on their transcripts (55%). Most of the prior biology course-taking experience of Black/African American students, was at the 100-level (36%) but a small number had 200-level experience (18%). The students who choose not to report their race or ethnicity had the highest level of 200-level biology experience (28%) and the students who were in the American Indian and Other Races/Ethnicities category had no 200-level biology experience prior to enrolling in the first course in major's level biology (see Figure 16).

Figure 16

Students Entering the First Course in Major's Biology Sequence with Prior Coursework in Biology Disaggregated by Race and Ethnicity (N = 342)

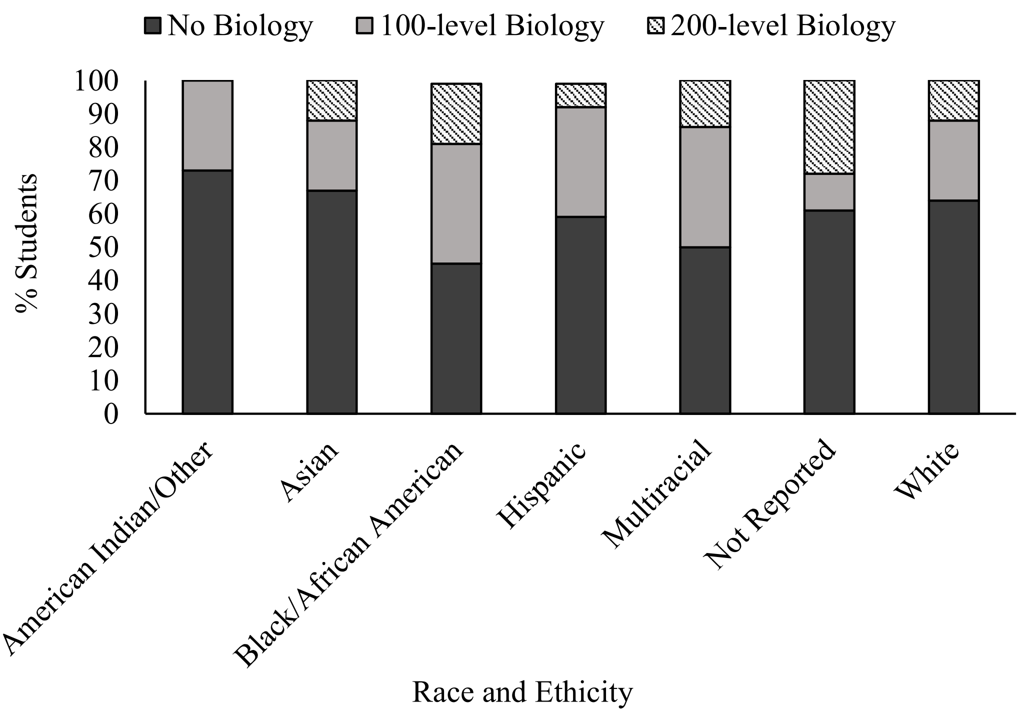


Table 20 includes the mean, standard deviation, and sample size for the number of college-level biology credits earned with a C or better, by students prior to enrolling in the first course in the major's biology sequence

Table 20

Credits College-level Biology Earned Prior to Enrolling in First Course in Major's Biology Sequence (N = 342)

Race and Ethnicity	*M*	*SD*	*n*
American Indian and other races/ethnicities[a]	1.07	1.83	15
Asian	3.30	6.26	33
Black/African American	4.36	5.46	11
Hispanic	3.59	5.77	27
Multiracial	4.18	5.31	22
Not reported	4.89	6.85	18
White	3.25	5.62	216

Notes. A 100-level lecture/lab class is four credits, a 200-level lecture/lab class is five credits.

[a]Students who identified as American Indian, Hawaiian Pacific Islander and nonresident alien.

All categories of race and ethnicity in the study were compared using a one-way ANOVA. There were no significant differences between students in different categories of race and ethnicity based on the average number of college-level biology credits earned prior to enrolling in the first course in the major's biology sequence ($F(6,335) = .79$, $p = .58$).

Most students in all the race and ethnicity categories except Hispanic entered the first course in the major's biology sequence with some prior college-level chemistry coursework on their transcript (see Figure 17). Under half (44%) of the Hispanic students had some prior college-level chemistry coursework. Most of the Asian students (58%) had 200-level chemistry. The multiracial students also had a high proportion (45%) of chemistry course experience at the 200-level. Black/African American students had the bulk of their experience (45%) at the 100-level prior to enrolling in the first course in the major's biology sequence (see Figure 17).

Figure 17

Students Entering the First Course in Major's Biology Sequence with Prior Coursework in Chemistry Disaggregated by Race and Ethnicity (N = 342)

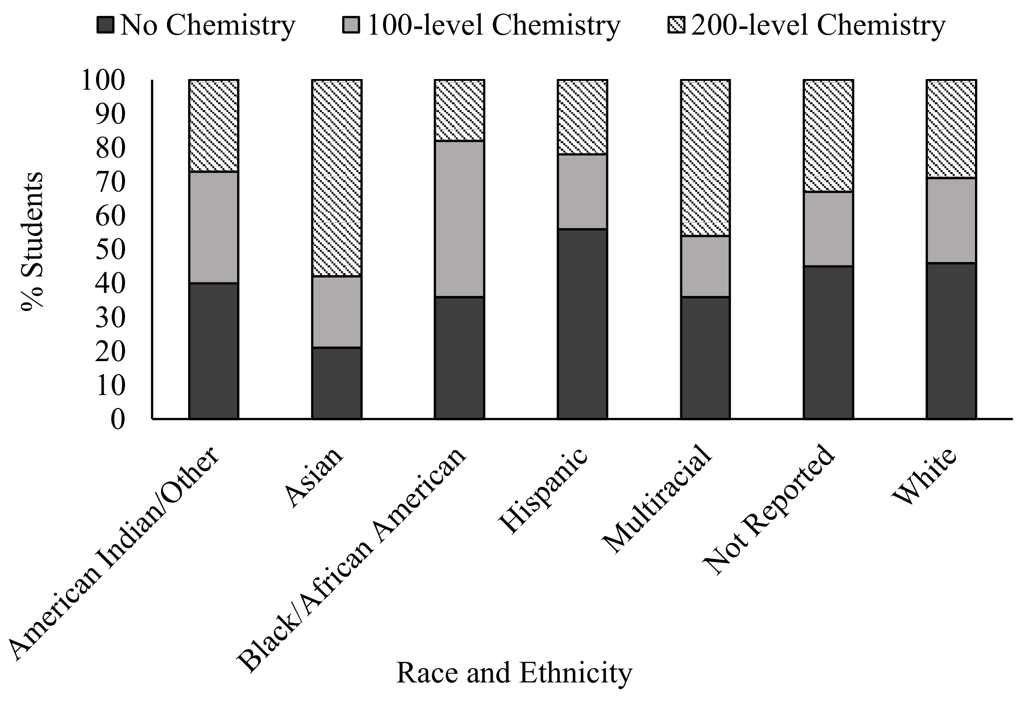


Table 21 includes the mean, standard deviation, and sample size for the number of college-level chemistry credits, earned with a C or better, by students prior to enrolling in the first course in the major's biology sequence.

Table 21

Credits College-level Chemistry Earned Prior to Enrolling in First Course in Major's Biology Sequence (N = 342)

Race and Ethnicity	*M*	*SD*	*n*
American Indian and other races/ethnicities[a]	5.47	8.45	15
Asian	7.00	5.51	33
Black/African American	5.27	6.29	11
Hispanic	3.30	4.55	27
Multiracial	5.68	5.41	22
Not reported	4.61	5.55	18
White	4.82	5.76	216

Notes. A 100-level lecture/lab class is four or five credits, a 200-level lecture/lab class is five credits.

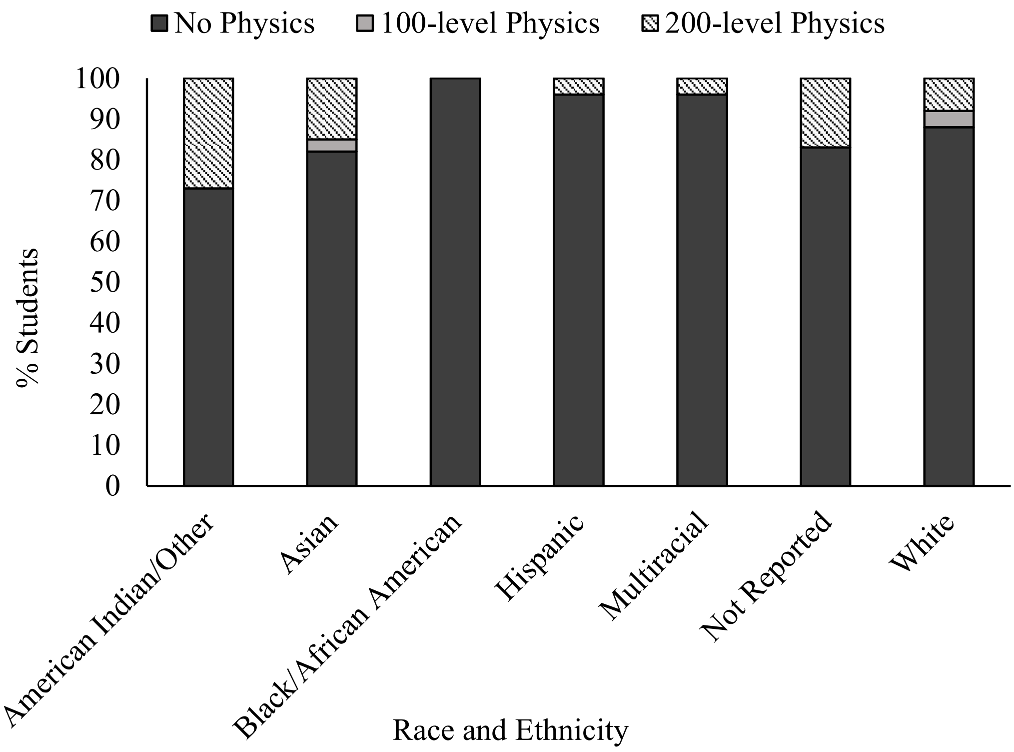
[a]Students who identified as American Indian, Hawaiian Pacific Islander and nonresident alien.

All categories of race and ethnicity in the study were compared using a one-way ANOVA. There were no significant differences between students in different categories of race and ethnicity based on the average number of college-level chemistry credits earned prior to enrolling in the first course in the major's biology sequence ($F(6,335) = 1.17$, $p = .32$).

Most of the students in all the race and ethnicity categories entered the first course in the major's biology sequence with no prior college-level physics coursework on their transcript (see Figure 18). A small number of students (27%, $n < 5$) who identified in the category of American Indian or Other Races/Ethnicities, had 200-level physics coursework prior to enrolling in the first course in the major's biology sequence. The Black/African American students had no prior physics course-taking experience.

Figure 18

Students Entering the First Course in Major's Biology Sequence with Prior Coursework in Physics Disaggregated by Race and Ethnicity (N=342)



The differences in physics course-taking behavior by race and ethnicity reflect that overall a very low number of physics courses were taken by students in all, with a total of 26 students taking one physics course prior to, and only 14 students taking more than one physics course prior to, enrollment in the first term of major's biology (N = 342). Table 22 includes the mean, standard deviation, and sample size for the number of college-level physics credits, earned with a C or better, by students prior to enrolling in the first course in the major's biology sequence disaggregated by race and ethnicity.

Table 22

Credits College-level Physics Earned Prior to Enrolling in First Course in Major's Biology Sequence (N = 342)

Race and Ethnicity	*M*	*SD*	*n*
American Indian and other races/ethnicities[a]	2.33	4.53	15
Asian	1.55	3.88	33
Black/African American	0.00	0.00	11
Hispanic	0.15	0.77	27
Multiracial	0.18	0.85	22
Not reported	1.11	3.00	18
White	0.70	2.28	216

Notes. A 100-level lecture/lab class is four credits, a 200-level lecture/lab class is four or five credits.

[a]Students who identified as American Indian, Hawaiian Pacific Islander and nonresident alien.

All categories of race and ethnicity in the study were compared using a one-way ANOVA. There was a significant difference between students in different categories of race and ethnicity based on the average number of college-level physics credits earned prior to enrolling in the first course in the major's biology sequence ($F(6,335) = 2.3$, $p = .04$). The effect size was weak (*eta-squared* = .04) (Muijs, 2016).

The major's biology sequence had a math prerequisite, so all students would have entered the class with Intermediate Algebra, a pre-college class, unless they tested out of the math requirement or an instructor waived the pre-requisite for an individual student. The course-taking pattern prior to enrollment in the first course in the major's biology sequence therefore represents only the math courses on the student's transcript. For the students with math courses on their community college transcript, most students in all the race and ethnicity categories had some college-level math prior to enrolling in the first course of major's level biology (see Figure 19). There were some differences in the level of college math taken. Most of the Asian (52%) and multiracial (59%) students had 200-level math. The majority of Black/African American (57%) and non-reporting students (60%) had 100-level math prior to enrolling in the first course in the major's biology sequence (see Figure 19).

Figure 19

Students Entering the First Course in Major's Biology Sequence with Prior Coursework in Math Disaggregated by Race and Ethnicity (N =231)

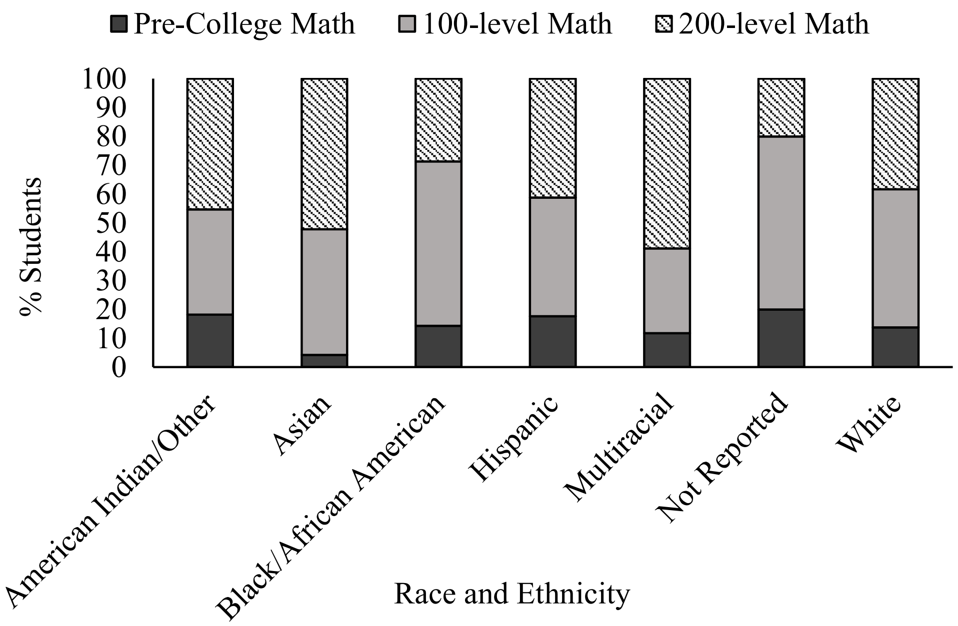


Table 23 includes the mean, standard deviation, and sample size for the number of college-level math credits earned with a C or better by students prior to enrolling in the first course in the major's biology sequence.

Table 23

Credits College-level Math Earned Prior to Enrolling in First Course in Major's Biology Sequence (N = 231)

Race and Ethnicity	*M*	*SD*	*n*
American Indian and other races/ethnicities[a]	4.40	4.81	15
Asian	6.67	6.22	33
Black/African American	4.82	6.88	11
Hispanic	5.19	6.21	27
Multiracial	7.82	6.14	22
Not reported	3.78	5.40	18
White	5.61	6.18	216

Notes. A 100-level lecture class is four or five credits, a 200-level lecture class is four credits.

[a]Students who identified as American Indian, Hawaiian Pacific Islander and nonresident alien.

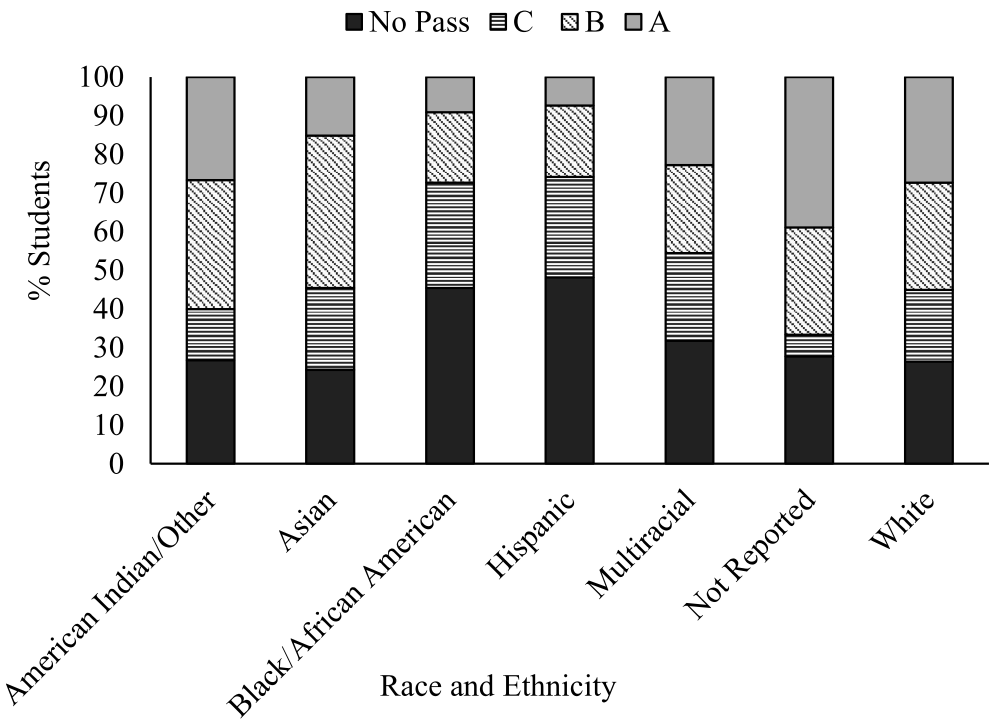
All categories of race and ethnicity in the study were compared using a one-way ANOVA. There were no significant differences between students in different categories of race and ethnicity based on the average number of college-level math credits earned prior to enrolling in the first course in the major's biology sequence ($F(6,335) = 1.06$, $p = .39$).

Grade Distributions in Major's Biology Sequence Disaggregated by Race and Ethnicity

Examination of the grade distributions disaggregated by race and ethnicity indicate dissimilar distribution patterns on the first attempt for all three courses in the major's biology sequence. Students who were represented in the American Indian and Other Races/Ethncities (73%, $n = 11$), did not report (72%, $n = 13$), identified as Asian (76%, $n = 25$), Multiracial (68%, $n = 15$) or, White (74%, n = 159), completed the first course in the major's biology sequence at higher levels compared to students who identified as Black/African-American (54%, *n* = 6), or Hispanic (52%, *n* = 14) (see Figure 20).

Figure 20

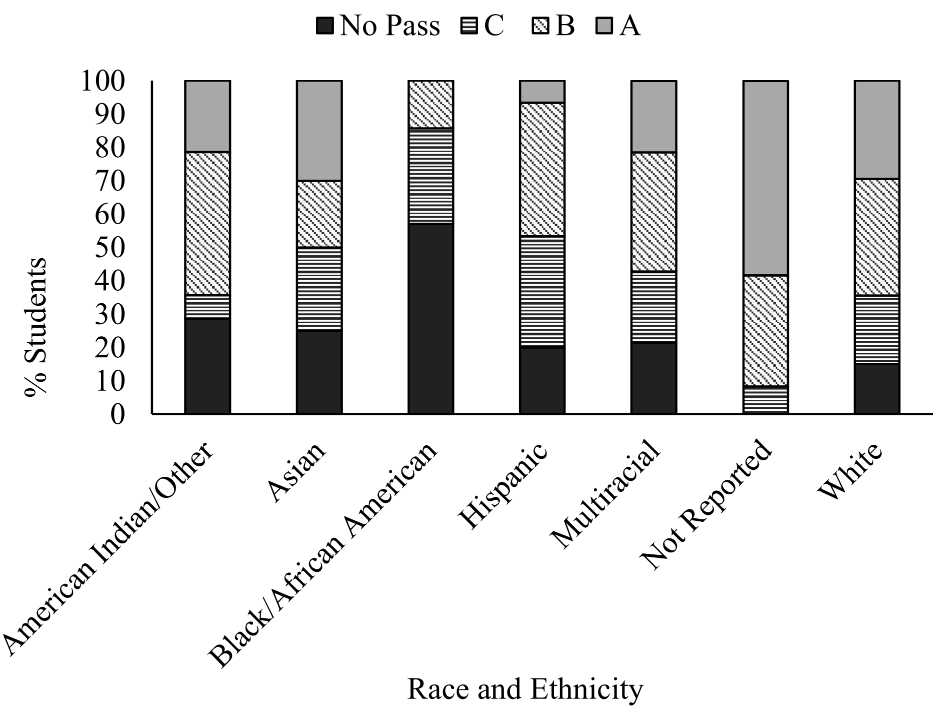
Grade Distribution in First Course in Major's Biology Sequence disaggregated by Race and Ethnicity (N = 342)



The trend towards dissimilar grade distribution patterns on the first attempt continued for the second course in the major's biology sequence. These data include students who may have repeated the first course several times and continued to the second course, once they had received a passing grade. Students who attempted the second course in the major's biology sequence tended to complete at higher rates with some exceptions. Students who identified as Hispanic (80 %), Multiracial (79%), did not report (100%) or who identified as White (84%), completed the second course at higher levels compared to the first course in the sequence. Students who were represented in the category of American Indians and Other Races/Ethnicities (71%) or who identified as Asian (75%) completed the second course at slightly lower but very similar levels compared to the first. The students who identified as Black/African American showed the largest drop in completion levels, 43% in the second course compared to 54% in the first (see Figure 21).

Figure 21

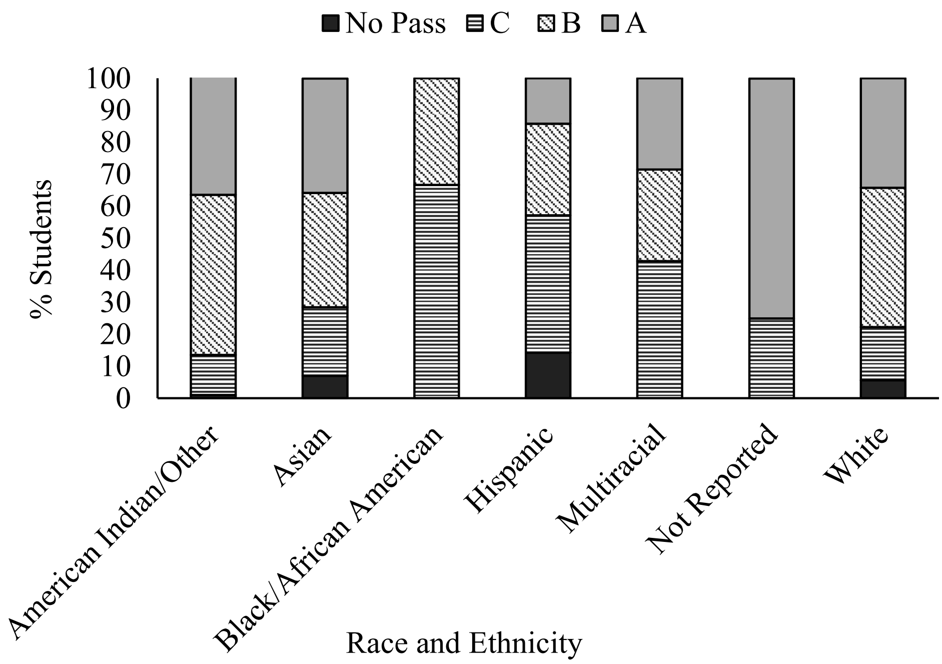
Grade Distribution in Second Course in Major's Biology Sequence disaggregated by Race and Ethnicity (N = 228)



The differences in grade distribution patterns on the first attempt appeared to narrow for the third course in the major's biology sequence (see Figure 22). Students in all categories of race and ethnicity showed higher levels of completing the third course in the sequence compared to the second and the first. More students who identified as Hispanic (86%) completed the third class compared to the second. All other categories of race and ethnicity showed levels of completing the third class of 93% or higher. The biggest change in the trend towards completion was by the students who identified as Black/African American (100%), all of whom completed the third class. It is important to note that these completion rates for all categories represent the students remaining in the class and a reduced sample size.

Figure 22

Grade Distribution in Third Course in Major's Biology Sequence Disaggregated by Race and Ethnicity (N = 169)

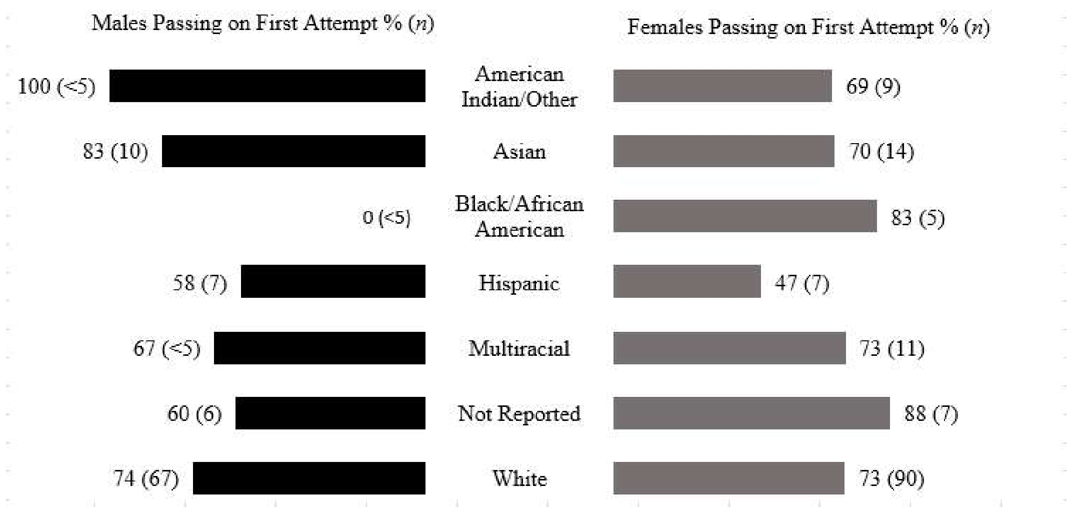


Completion of the Major's Biology Sequence Disaggregated by Race and Ethnicity and Gender

The grade distribution patterns for students disaggregated by race and ethnicity, changed markedly over the three-term sequence of major's biology. To try to describe the patterns more fully, the completion rates in each of the major's level biology courses were examined disaggregating the data by race, ethnicity, and gender. Figure 23 shows the levels of successful completion in the first course in the major's biology sequence by race and ethnicity and compares males and females within each category. Some striking trends emerge that show a very different pattern of completion for male and female Black/African American students, where none of the males completed the first course in the major's level biology class on the first attempt compared to 83% of the female students. All the Black/African American males attempted the course a second time. Fewer male students identifying as multiracial or who did not report completed compared to corresponding female students, but the differences were not as large (see Figure 23).

Figure 23

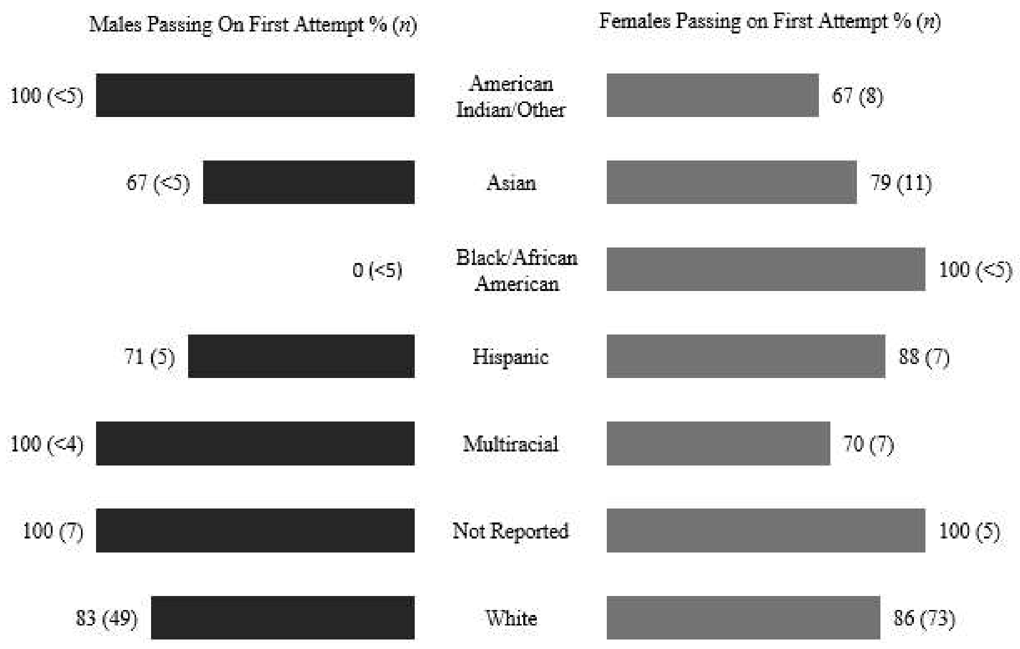
Students Completing First Course in Major's Biology Sequence on First Attempt Disaggregated by Gender, Race, and Ethnicity (N = 342)



The levels of successful completion in the second course in the major's biology sequence by race and ethnicity, and comparing males and females within each category, are shown in Figure 24. The differences in the pattern of completion between Black/African American males and females remain, with none of the males completing the second course in the major's level biology on the first attempt compared to all the females. The differences between male and female students in other categories did not maintain a consistent trajectory. Fewer female multiracial students were now completing compared to males, and all the students who did not report completed the second course. Fewer Asian, Hispanic, and White males also completed the second course in the biology sequence, but the disparities were not large.

Figure 24

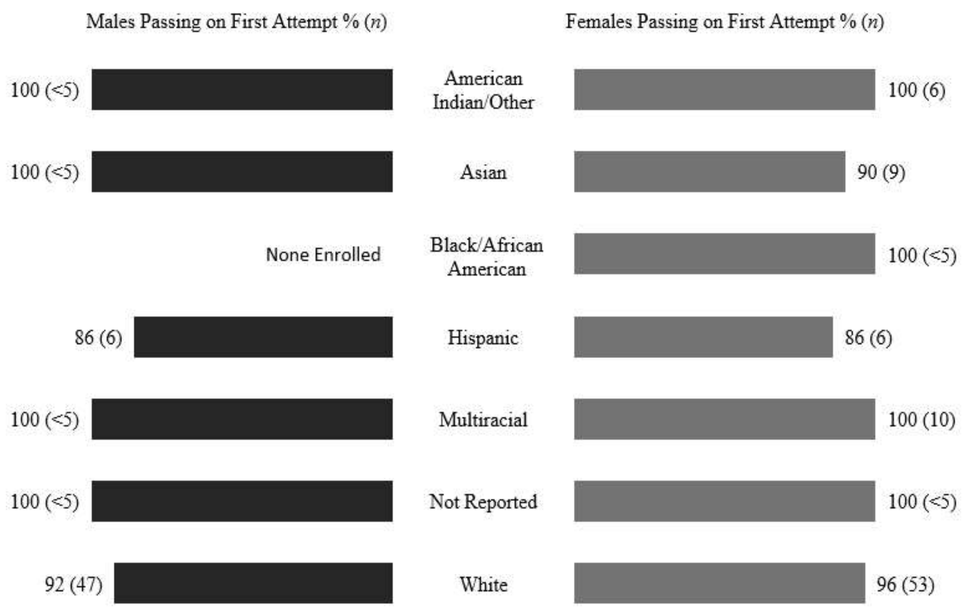
Students Completing the Second Course in Major's Biology Sequence on First Attempt Disaggregated by Gender, Race and Ethnicity (N = 228)



The levels of successful completion in the third course in the major's biology sequence by race and ethnicity and comparing males and females within each category are shown in Figure 25. Completion patterns between male and female students in all race and ethnicity categories are very similar in the third course of the major's biology sequence, with a 10% difference or less. However, it is important to note that the Black /African American males are no longer represented in the sample. Most of the Black /African American males in the sample did attempt the second class in the sequence a second time (75%, $n < 5$), but none enrolled in the third class. These data do not represent a sample size large enough to infer statistical significance, but they represent a pattern of completion and enrollment that raises critical questions about the experience of Black/African American males in the major's biology sequence. This finding will be further discussed in Chapter 5.

Figure 25

Students Completing the Third Course in Major's Biology Sequence on First Attempt Disaggregated by Gender, Race and Ethnicity (N = 169)

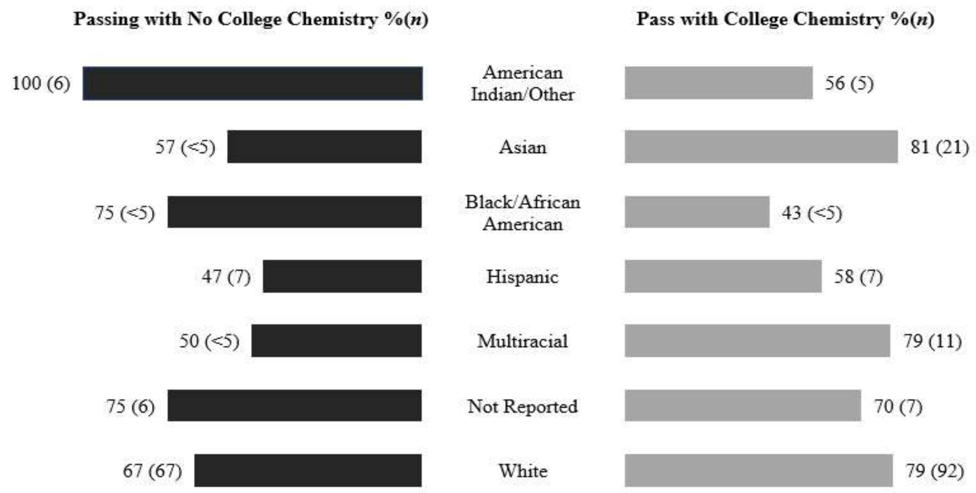


Completion of Major's Biology Sequence Disaggregated by Chemistry Preparation, Race, Ethnicity, and Gender

The relationship between course-taking behavior, completion and the first course in the major's biology sequence was discussed in research question two. There was a significant difference in the number of students who completed the first term on their first attempt based on their category of prior chemistry course taking behavior ($\chi^2(3, N = 342) = 8.414, p = .04$), (see figure 7). Noting once again that the design of this study is non-experimental and that causal relationships should not be inferred (see Figure 26), juxtaposes the proportion of students completing the first course in the major's biology class with no college chemistry on their transcripts with the proportion of students completing with college chemistry on their transcripts disaggregated by race and ethnicity. The proportion of students who were in the American Indian and Other Races/Ethnicities and Black/African American categories of race and ethnicity completing the first major's biology course with college chemistry was lower than the proportion completing major's biology without college chemistry (see Figure 26). This finding raises questions about the role of experience with high school chemistry, which was unknown and the role of 200 versus 100-level college chemistry in preparing students for major's level biology. The sample sizes were very small, so the trends should be interpreted cautiously.

Figure 26

Completion of the First Course in Major's Biology Sequence on First Attempt Disaggregated by Chemistry Preparation, Race, and Ethnicity (N = 342)

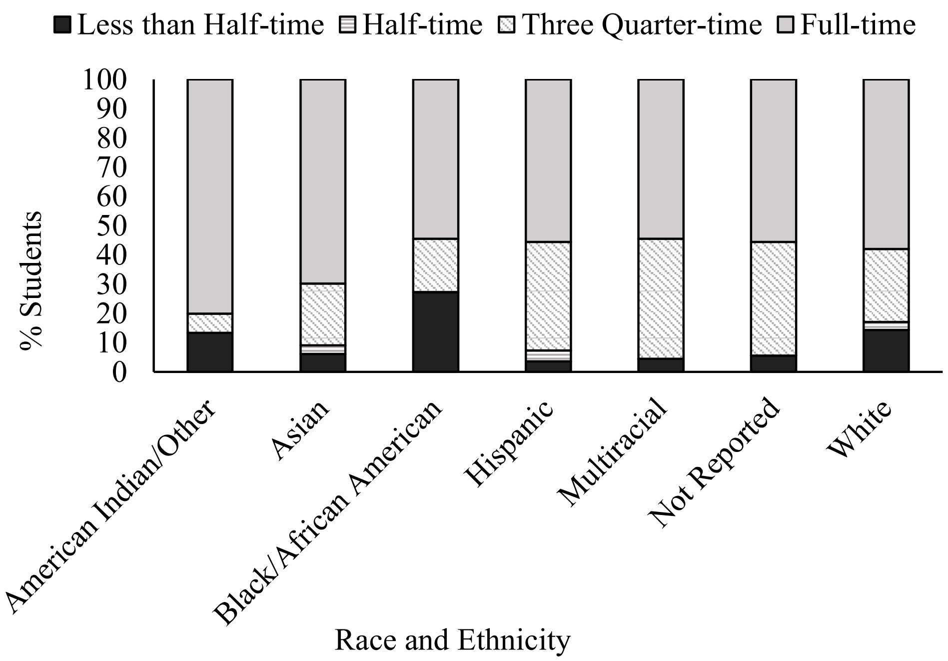


Enrollment Intensity Disaggregated by Race and Ethnicity

There was a wide range in the number of credits the students were enrolled in the first term of the major's biology sequence during the 2014/15 academic year (range 5 to 19 credits). There was not a large range in the average number of credits enrolled in between students in different categories of race and ethnicity (see Figure 27). Hispanic students had highest average enrollment intensity based on credits (M = 12.52, SD = 3.31) and Black/African American students had the lowest average enrollment intensity based on credits (M = 10.55, SD = 3.88). All categories of race and ethnicity in the study were compared using a one-way ANOVA. There were no significant differences between students in different categories of race and ethnicity based on the intensity of enrollment measured by the number of enrolled credits during the term the student was enrolled in the first course in the major's biology sequence ($F(6,335) = 59$, $p = .74$).

Figure 27

Enrollment Intensity During First Attempt at Major's Biology Sequence Disaggregated by Race and Ethnicity (N = 342)



Research Question Four

What was the relationship between the course-taking behavior in a biology-related degree sequence and predicting transfer to a four-year institution into a biology or biology-related degree track?

Predictive Value of Course-Taking Behaviors for Transfer Outcome

A logistic regression model (Hosmer et al., 2013) was constructed to examine the relationship of course-taking behaviors to successful transfer to a four-year institution, for the cohort of students taking the first course in the biology major's sequence in the 2014/15 academic year. The selection of variables to investigate was based on previous research (Bahr, 2013b; Chan & Wang, 2018; Cohen & Kelly, 2020; Wang, 2013a; Wang et al., 2019; Wang, Wang, et al., 2017) and a purposeful selection process (Bursac et al., 2008). These variables included: biology, chemistry, physics and math course-taking prior to enrollment in the first course of the major's biology sequence; first term major's biology course grade on first attempt, and enrollment intensity during the term enrolled in the first course in the major's biology sequence.

Purposeful selection (Bursac et al., 2008; Hosmer et al., 2013) was used to choose candidates as covariates to fit an initial multinomial logistic regression model. Screening for variables to put in the model was done using likelihood ratio tests from univariate logistic regression analyses with a conservative screening level of $p < .25$ (Mickey & Greenland, 1989). Using this method, the following course-taking variables were identified for the initial model: credits of 100-level biology, 200-level biology, 200-level chemistry, pre-college math, and 200-level math earned prior to enrollment in the first course in the major's biology sequence; as well as the enrollment intensity in the term the student first attempted major's level biology (see Table 24). Students who did not report gender were excluded from the analysis to maintain confidentiality. Students for whom no NSC enrollment records were available, and so transfer outcomes could not be assigned, were also excluded from the analysis. Tests of the variables for all models were carried out using only participants whose information was complete for all variables ($N = 336$).

Table 24

Likelihood Ratio Tests from the Univariate Logistic Regression for Inclusion of Independent Variables

Course-taking	*N*	χ^2	*df*	*p*
Credits 100-level biology	336	5.04	3	$.17^{\dagger}$
Credits 200-level biology	336	12.29	3	.006**
Credits 100-level chemistry	336	2.33	3	.53
Credits 200-level chemistry	336	5.41	3	$.14^{\dagger}$
Credits 100-level physics	336	2.70	3	.44
Credits 200-level physics	336	1.98	3	.58
Credits pre-college math	336	5.57	3	$.13^{\dagger}$
Credits 100-level math	336	2.96	3	.40
Credits 200-level math	336	6.65	3	$.08^{\dagger}$
Gap between first and second course in major's biology	336	2.94	3	.40
Enrollment intensity term first attempted major's biology	336	10.16	3	.02**
Grade first attempt first course major's biology	336	16.46	3	.001**
Gender	336	.772	3	.86
Age	336	6.50	3	$.09^{\dagger}$
Race and ethnicity	336	3.68	3	.30

Notes. .$^{\dagger}p < 0.25$, *$p < .05$,**$p < .01$.

No Transfer as reference category for logistic regression model.

Building the Model

Using the variables identified through purposeful selection, the preliminary initial logistic regression model was run to determine the effects, on the likelihood of being in one of the four transfer categories, predicted by following course-taking variables: credits accumulated of 100-level biology, 200-level biology, 200-level chemistry, pre-college math, and 200-level math prior to enrollment in the first course in the major's biology sequence; as well as the enrollment intensity in the term the student first attempted major's level biology, grade first attempt in the first course of major's biology and age. The reference category was set to be no transfer. Credits of pre-college math accumulated was removed as a variable based on preliminary results that it was not a significant predictor in the initial model (χ^2 = 1.65(3), p = .65). In the subsequent revised model, credits of 100-level biology accumulated prior to enrolling in the first course in the major's biology sequence was no longer a significant predictor (χ^2 = 7.16(3), p = .07) and was removed from the model, as was age (χ^2 = 6.42(3), p = .09). Additional runs with these variables removed led to removing 200-level Math and then 200-level Chemistry to create the most parsimonious model. The logistic regression model including the remaining variables as predictors was significantly better at explaining the variance in the data than the baseline model with no predictors (χ^2 = 38.79(9), p < .001). The model correctly classified 43% of cases overall. The model correctly classified 79% of the cases transferring into a biology or biology-related discipline, 24% of cases as no transfer, 18% cases of transfer not biology and 11% of cases correctly as transfer into a professional or graduate program. Neither the Pearson (χ^2 = 196.68(234), p = .96) nor the Deviance (χ^2 = 179.61(234), p = .997) Goodness-of-fit were significant, indicating that there was no significant difference between the predicted and observed data, and the model was a good fit. The generalized Hosmer-Lemeshow goodness-of-fit test was also not significant (χ^2 = 10.50(24), p = .99), confirming that the observed results were not significantly different than those predicted by the model (Fagerland & Hosmer, 2012).

The likelihood ratio tests for the contribution of each covariate as a predictor in the overall model indicated that all were significant (α = .05) to the overall model (see

Table 25). Checks for interactions between variables were carried out and none were found to contribute significantly to the main effects model. A review of the pseudo R^2 values suggested that the model with predictors significantly explained more of the variance in the data and represented a modest effect or improvement over the baseline model (Cox & Snell = .11; Nagelkerke = .12) (Muijs, 2016).

Table 25

Likelihood Ratio Tests for Individual Predictors in Final Logistic Regression Model

Course-taking	*N*	χ^2	*df*	*p*
Credits 200-level biology	336	11.90	3	.008*
Enrollment intensity term first attempted major's biology	336	10.51	3	.015*
Grade first attempt first course major's biology	336	16.45	3	.001*

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

No Transfer as reference category for logistic regression model.

Tests of Model Assumptions

Logistic regression models assume that the outcomes are not biased by collinearity between the independent variables, and that there is a linear relationship between the continuous variables and the logit of the dependent variable. Tests for multicollinearity were run to identify variables that had unacceptable levels of correlation and would violate the assumptions of the logistic regression model (Field, 2018). None of the tolerance levels were less than .1 (Menard, 1995) and all variance inflation factor (VIF) values were below 2, indicating acceptable levels of correlation between the covariates (Myers, 1990).

Finally, a Box-Tidwell Test (Field, 2013) was used to confirm the linear relationship between the continuous independent variables and the natural log of the outcome variable (logit). The interactions between each continuous independent variable and its natural logarithm were not significant when added to the model, indicating that the assumptions of linearity were not violated for the variables included in the model.

Contributions of Predictors

The logistic regression model was significantly better at explaining the variance in the data-than the baseline model with no predictors (χ^2 = 38.79(9), $p <$ .001). The predictor factors included: credits accumulated of 200-level biology prior to enrollment in the first course in the major's biology sequence; as well as the enrollment intensity in the term the student first attempted major's level biology and the grade earned in the first course of major's biology on the first attempt. All predictors were significant in the overall model (see Table 26). The relationship of each variable to the different categories of transfer outcome was more complex, indicating that different variables contributed in different ways for each of the transfer outcome categories (see Table 26). Variables that were significant predictors of the category of transfer compared to no transfer were determined using the Wald statistic.

Transfer to a Program that was Biology or Biology-related

The contribution of predictors to different transfer outcomes varied within the model. The grade in the first term of major's biology on the first attempt was a significant predictor of transfer into a program that was biology or biology-related (*B*

= .27, (*SE* = .12) Wald = 4.86, *p* = .03) compared to not transferring to a four-year institution. The estimated odds ratio (Exp(*B*) = 1.31) indicated that for every additional increase in grade level, the odds were 1.31 times higher of transferring into a biology-related program compared to not transferring.

Transfer to a Program that was Non-biology-related

None of the variables in the model were predictors of transferring into a program that was not biology or biology related.

Transfer to a Professional or Graduate Program

The grade in the first term of major's biology on the first attempt was a significant predictor of transfer into a program that was a graduate or professional program (*B* = 1.70, (*SE* = .62) Wald = 7.55, *p* = .006) compared to not transferring to a four-year institution. The estimated odds ratio (Exp(*B*) = 5.50) indicated that for every additional increase in grade level, the odds were 5.50 times higher of transferring into a professional or graduate compared to not transferring. This would be consistent with the competitive nature of graduate programs. In addition, the enrollment intensity or number of credits a student was attempting during the first major's biology was a significant predictor (*B* = -.33, (*SE* = .11) Wald = 9.77, *p* = .004). A student was predicted to be less likely to transfer into a professional or graduate program the more credits they were taking. The estimated odds ratio (Exp(*B*) = .72) indicated that for every additional credit a student attempted the term they were taking major's biology they were .72 times as likely to transfer into a graduate or professional program, or that students carrying higher credit loads were less likely to transfer (see Table 26).

Table 26

Multinomial Logistic Regression Model for Predicting Transfer Outcomes Based on Course-taking

Transfer Pathway	Indicators	*B*	*SE*	Wald	*df*	Sig.	Exp(*B*)	95% Confidence Interval for Exp(B) Lower Bound	95% Confidence Interval for Exp(B) Upper Bound
Transfer to Biology or Biology-related Program	Intercept	.121	.524	.053	1	.818			
	Grade First Major's Course	.270	.123	4.858	1	.028*	1.310	1.030	1.666
	Credits 200-level Biology	-.078	.052	2.216	1	.137	.925	.835	1.025
	Enrollment Intensity Term First Attempt Major's Biology	-.010	.039	.061	1	.804	.990	.918	1.069
Transfer to a Non Biology-related Program	Intercept	-.157	.553	.081	1	.776			
	Grade First Major's Course	.150	.128	1.389	1	.239	1.162	.905	1.493
	Credits 200-level Biology	.060	.039	2.376	1	.123	1.062	.984	1.147
	Enrollment Intensity Term First Attempt Major's Biology	-.001	.041	.000	1	.982	.999	.922	1.083
Transfer to a Professional or Graduate Program	Intercept	-2.821	1.779	2.514	1	.113			
	Grade First Major's Course	1.705	.620	7.555	1	.006**	5.504	1.631	18.570
	Credits 200-level Biology	.052	.077	.460	1	.498	1.053	.907	1.224
	Enrollment Intensity Term First Attempt Major's Biology	-.329	.115	8.214	1	.004**	.720	.575	.901

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

No Transfer as reference category for logistic regression model.

Summary

Chapter four presented the results of the study to investigate the relationship of course-taking patterns by community college students enrolled in major's biology to successful transfer. A summary of the findings for the four research questions that guided this study is presented.

Research Question One

An examination of how leading indicators that predict successful transfer to a four-year institution, identified for community college students in general, applied to students in a biology transfer sequence at a large western community college suggested that first term GPA, was predictive of transfer. Additionally, accumulation of credits associated with the biology MTM in the first year, and completing college-level math in the first year were effect modifiers. The relationship was not strong or consistent across categories of transfer outcome suggesting that further research is needed to fully understand the complex relationship of academic momentum and transfer outcomes for this population of students.

Research Question Two

Students had a broad range of prior coursework in biology, chemistry, physics, and math prior to enrolling in the first class in the major's sequence. Prior course work in biology, chemistry and math were related to statistically significantly better outcomes in the major's biology sequence. Physics was the exception, with most students not having taken physics prior to major's biology. Completion rates increased as students progressed through the three-term sequence of major's biology, although the overall attrition was high. Some students attempted the first course in the major's sequence multiple times. Most students who continued in the major's biology sequence took the next class in the following term. Students ranged broadly in how many credits they were taking in the term the took major's biology. The average credit load was close to a full course load, but the bulk of students were either carrying a full course load or just one course.

Research Question Three

Disaggregation of the course-taking behavior by gender, age, race, and ethnicity revealed very few differences between male and female students except for enrollment intensity. Fewer women were enrolled full-time compared to men. There were statistically significant differences in prior course work based on age for biology, chemistry, and math but not for physics. The grade distributions were not different based on age group for the first or third course in the major's biology sequence, but they were significantly different for the second course. Fewer students older than 30 years were enrolled full-time compared to students in the younger age categories. Most of the students older than 30 years taking just one class a term were female. This contrasts to the enrollment intensity patterns for traditional age students, 23 years or younger where most of the female students were enrolled full-time. There were no significant differences in credits earned prior to taking major's biology in biology, chemistry, or math between students in different categories of race and ethnicity. There were statistically significant differences seen in physics course taking although the overall level of physics course work was very small. The sample sizes for some of the categories of race and ethnicity were too small to make statistical comparisons but trends suggested disparities in the distribution of grades and completion. Data disaggregated further by race, ethnicity and gender raised equity questions about the experience of Black/African American males in the major's biology sequence.

Research Question Four

An examination of how the course-taking behaviors related to prior course work in biology, chemistry, and math, and enrollment intensity, applied to students in a biology transfer sequence at a large western community college suggested that some of these variables were good predictors of transfer outcomes. Accumulation of 200-level credit in biology, grade in the first course in major's biology and number of credits carried during the term major's biology was first attempted, were covariates in the most parsimonious fitted logistic regression model. A higher grade in the first course in the major's biology course was related to higher odds of transferring into a biology-related program or into a professional or graduate program. Lower levels of enrollment intensity were related to higher odds of transferring into a professional or graduate program. The trends were similar for transfer to a non-biology related program but none of the predictors were statistically significant for that transfer category.

The implications of the research findings presented in this chapter are discussed in chapter five. Additionally, connections with prior research and limitations of the study are also discussed. Chapter five concludes with recommendations for future research.

Chapter 5: Discussion

The purpose of this quantitative study was to investigate the relationship of course-taking patterns of community college students enrolled in biology courses to successful transfer into a biology or biology-related degree track at four-year institutions. The study investigated four research questions: (a) To what extent do the leading indicators that predict successful transfer to a four-year institution identified for community college students in general, also predict transfer outcomes for students in a biology transfer sequence at a large western community college? (b) What is the pattern of course-taking behavior of students in a biology-degree transfer sequence at a large western community college? (c) What is the pattern of course-taking behavior in a biology-degree transfer sequence for students disaggregated by gender, age, race, and ethnicity at a large community college in the west? and (d) What is the relationship between the course-taking behavior in a biology-related degree sequence and transfer to a four-year institution in a biology or biology-related degree track?

This chapter will discuss the results of this study, which have implications for curriculum development, implementation of biology transfer maps in guided pathways reform initiatives, and support services related to advising community college students in a biology transfer sequence. The predictive value of some, but not all, leading indicators of academic momentum identified in previous research (Adelman, 1999, 2006; Attewell et al., 2012; Belfield et al., 2019; Jenkins et al., 2018; Witteveen & Attewell, 2017) for first-time college-age students was confirmed for the more heterogenous group of students tracked in this study. The examination of the course-taking behavior for the group of students tracked in this study also suggests additional metrics specific to biology as leading indicators for transfer success. The identification of additional predictors reinforces the importance of the disciplinary context for assessment of leading indicators of success (Belfield et al., 2016; Calcagno et al., 2008; Wang, 2016b). The findings indicate the importance of achievement in the first course in major's biology for a student's academic momentum towards transferring successfully. The relationship between college course-taking behavior in STEM prior to enrolling in major's biology and outcomes is documented. Differences in course-taking patterns based on gender, age, race and ethnicity are explored. Consistent with the national conversation about the opportunity gaps for Black/African American males (Riegle-Crumb et al., 2019; Wood, 2012), the findings of this study also raise additional questions related to the experiences of historically underserved students in major's biology who indicated an interest but who were not retained. Further research that builds on the findings of this study will be important for increasing the engagement of a broader range of students in biology, particularly in historically under-represented groups. This chapter will discuss the findings identified in Chapter 4, organized by research question.

Research Question One

Leading Indicators of Academic Momentum as Predictors in a Logistic Regression Model

Leading indicators of academic momentum were fit to a logistic regression model to determine their value for predicting transfer outcomes in the groups of students studied. First term GPA was a significant predictor (χ^2 = 9.20(3), p = .027) of successful transfer to a four-year institution. This is a leading indicator previously identified for community college students in general to predict successful transfer to a four-year institution (Cohen & Kelly, 2019b; Zhang, 2019). This finding was based on a multinomial logistic regression model where a significant loglikelihood ratio (χ^2 = 19.11(9), p = .02) indicated that the model with predictors was significantly better at explaining the variance in the data than the baseline model with no predictors. The model included first term GPA, accumulation of credits associated with the biology MTM in the first year, and completing college level math in the first year as predictors.

The accumulation of credits associated with the biology MTM, in the first year, and completing college level math in the first year, were not significant predictors in the overall model but were found to be effect modifiers (Field, 2018; Hosmer et al., 2013) and so these variables were included in the final model. The predictive value of first term GPA for the heterogenous population of community college students in a biology transfer sequence is consistent with previous demonstrations of the connection between GPA and college student success. For instance, McCormick and Carroll (1999) found a significant (p < .05) association between first year GPA and degree completion for students at a four-year institution. This finding is consistent with the predictive value of GPA for transfer and degree completion demonstrated for a group of community college students in New York State (Cohen & Kelly, 2019b). Previous research by Zhang (2019), also demonstrated that a group of community college students in Texas were more likely to subsequently complete a STEM degree at a four year institution if they had higher GPAs. This study extends those previous findings to support the predictive value of first-term GPA for a sample of community college students that was heterogenous in terms of age and prior college experience.

Some authors (i.e., Attewell et al., 2012) have critiqued the use of GPA as a leading indicator for academic momentum suggesting that grades are an effect rather than an element of academic momentum. This perspective is valuable to consider given that the model proposed by this study also included completing college math the first year and accumulation of program credits in the biology major's transfer map in the first year because they were effect modifiers. The finding that completing college math the first year and accumulation of program credits in the biology major's transfer map are effect modifiers is intuitive because a failed attempt at a college-level math class or completing the STEM classes on the biology major's transfer map may be components of the first term GPA. The patterns of course taking that contribute to student GPA remain an important consideration, which will be discussed further in this chapter under research question two.

It is important to note that the effect size of predictors in the model was small, and none of the variables were significant predictors specifically of transfer to a program that was biology or biology-related, compared to not transferring. There was a non-statistically significant trend (B = .03, (SE = .02) Wald = 2.92, p = .09) that suggested that an increase in credits accumulated in the biology major's transfer map increased the likelihood of transferring in a biology or biology related degree program (see Table 10). The lack of significance raises some questions about the importance of the relevance of the timing of courses for the group of students in the study, and of the calculation of leading indicators for academic momentum. Only 30% (*n* = 102) attempted the first course in the major's biology sequence in their first year of enrollment at the community college. Offenstein and Shulock (2010) suggest that adding a time frame gives a milestone of achievement that makes it a part of the student's academic momentum towards their educational goal. The time frame for leading indicators of academic momentum may need to shift as a student's goals change throughout their association with the institution. Students may enter without clear academic goals and the relevance of leading indicators to academic momentum towards a specific goal may be dependent on the development of that goal as students have experiences that change their intent to transfer (Wang, Lee, et al., 2017; Wang, Sun, et al., 2017). Helping students identify academic goals early and providing appropriate ongoing support such as advising, is part of how the reform models such as guided pathways can help support students to improve their academic momentum (Bailey et al., 2015). Tracking student goals in concert with their performance on leading indicators of academic momentum would assist advisors as they worked with students to stay on track for academic goals.

First term GPA as a Predictor for Transfer to a Professional or Graduate Program

First term GPA was a significant predictor (*B* = 2.03, (*SE* = 1.03) Wald = 3.90, *p* = .048) for transferring to a graduate or professional program compared to not transferring to a four-year institution. The group of students transferring into a professional or graduate program had the highest average first term GPA (*M* = 3.89, *SD* = .33) compared to students in the other categories of transfer outcome (see Figure 3). All the students in this category transferred into a professional or graduate program, in the health professions or related-clinical sciences. The association between GPA and successful transfer to a professional or graduate program may reflect the competitive nature of programs such as pharmacy, that students transferred into. This detail is pertinent because these data would not reflect unsuccessful applications to professional programs.

Completion of College Math as a Predictor for Transfer to a Professional or Graduate Program

Completing college math in the first year was also a significant predictor (*B*= 2.15, (*SE* = 1.03) Wald = 4.33, *p* = .04) for transferring into a graduate or professional program. The group of students transferring into a professional or graduate program had the highest level of completing college math in the first year (89%, *n* = 9) compared to students in the other categories of transfer outcome (see Figure 3). The finding that completing college level math is a predictor of transfer outcomes for the group of students studied is consistent with previous research (Belfield et al., 2019; Flanders, 2017; Hagedorn & DuBray, 2010), where completion of college-level gateway courses such as college-level math was a good predictor of success in a broader population of community college students.

Program Credits as a Predictor for Transfer to a Professional or Graduate Program

Accumulating program credits associated with the biology major's transfer map (MTM) was not a significant predictor ($p \geq .05$) variable for students transferring to a professional or graduate program. This finding is consistent with the evidence based on transfer outcome that majoring in biology was not the goal for this group of students.

Leading Indicators of Academic Momentum Not Included in Model

The additional leading indicators screened as potential predictors for fitting the logistic regression model were: (a) credit accumulation in the first term, first year, (b) completing major's biology in the first year, and (c) first-year enrollment intensity. These indicators were not predictive of transfer (see Table 8 and Table 9). This finding is not consistent with previous research (Adelman, 1999, 2005, 2006; Attewell & Monaghan, 2016; Belfield et al., 2019) where the rate of credit accumulation is a foundational element of academic momentum. Several elements of this study may have contributed to the differences observed. First, many of the previous studies have focused on first-time college students of traditional age (Adelman, 1999, 2005, 2006; Attewell et al., 2012; Attewell & Monaghan, 2016; Belfield et al., 2019). The present study included a representative mix of community college students, some of whom were not first-time college students, and the majority of whom (53%, $n = 183$) were of post-traditional age. Older students were carrying fewer credits (see Figure 15). It was not known if this was related to their work-status. Working more than 30 hours per weak was a mitigating factor in Attewell and Monaghan's (2016) study on the relationship of credit load to academic momentum towards degree completion. Differences in course-taking behavior dissagregated by age are discussed later in this chapter in research question three. Second, some of the students in the study had a long association with the community college. These students may have been accessing the institution for more than just the transfer function. Calculating the credit accumulation for the first year or the first term enrolled, when the student is perhaps taking a class for personal enrichment, may not have the same predictive value as calculating it when a student is accessing the institution for the transfer function.

Research Question Two

An examination of the patterns of course-taking behavior of students in a biology-degree transfer sequence at a large western community college found that students had a broad range of coursework in biology, chemistry, physics, and math prior to enrolling in their first major's biology course. Students had completed an average of 3.37 credits (*SD* = 5.63) of biology, 5.0 credits (*SD* = 5.79) of chemistry, .77 credits (*SD* = 2.52) of physics and 5.65 credits (*SD* = 6.12) of math, prior to the first attempt of the first course in the major's biology sequence. A single lecture and laboratory class combination in these disciplines ranged from four to five credits, depending on the level. It was evident that students were attempting the first course in major's biology with very different levels of experience with college-level STEM classes. This variation in course-preparation informs an understanding of the challenges inherent in creating equitable learning opportunities in the major's biology classroom.

Prior Biology Coursework and Outcomes

The number of prior biology classes ranged widely from zero to seven with 37% of students (n = 128) having some prior college-level biology on their transcript (see Table 10). Most of the students with prior college-level biology on their transcripts (66%, n = 85) had taken 100-level biology. High-school or 100-level biology is recommended, but the first course in the major's level biology has no biology prerequisites, and 100-level biology is not part of the biology major's program map for transfer (HECC, 2020). There was no significant difference in the number of students who completed the first-term of the major's biology sequence on their first attempt based on their category of prior biology course-taking behavior ($\chi^2(3, N = 342) = 5.95, p = .11$) raising some questions about the efficacy of the recommendation to take 100-level biology prior to enrolling in major's biology. It is important not to infer causality for these results, here and in the following discussions, because of the non-experimental design of the project, but the questions raised by the pattern of course taking do suggest the need for further consideration. The recommendation to take a 100-level biology course prior to enrolling in major's biology might account for some of the course taking patterns, but 20% (n = 68) of the students in the study had more than one previous biology course. Given that the excess accumulation of unnecessary credits has been identified as a barrier to completion for community college students (Monaghan & Attewell, 2015), this pattern of accumulation of 100-level biology credits points to an opportunity for targeted advising (Bailey et al., 2015). It may also suggest that a student is developing aspirations and STEM self-efficacy (Wang, 2017), based on their exploratory experiences in biology. Regardless, of the reason for the pattern, the documentation of the range of prior student experience with college-level biology in the classroom, calls for teaching strategies that promote equitable learning environments for students with variable STEM backgrounds.

Students who were in different course taking categories did receive significantly different grades in the first term of the major's biology sequence ($\chi^2(9, N = 342) = 19.19, p = .03$). The reality that 37% of the students in the first course in major's biology were entering with substantial content background may exacerbate a competitive environment (Holland, 2019) where first generation, female, and historically underrepresented students often experience imposter syndrome (Canning et al., 2020; Clance & Imes, 1978; Lindemann et al., 2016) or a lack of a sense of belonging (Rodriguez & Blaney, 2020). Information about the additional component of college preparedness, based on high school biology background, would be an important piece of information before making conclusions about whether the prior college biology course taking patterns exacerbated existing inequities or provided an opportunity for different groups of students to augment their high school backgrounds before attempting the first course in the major's biology sequence.

Prior Chemistry Coursework and Outcomes

The patterns of chemistry course-taking prior to students attempting the first course in the major's biology sequence raised the most questions about curricular alignments and equitable classroom learning environments. The 200-level chemistry class has a 100-level math prerequisite. The major's biology has a pre-college math prerequisite and a 100-level chemistry co-requisite. Most students (57%, $n = 194$) had begun their chemistry preparation before attempting the first course in the major's biology sequence (see Figure 7). The significant difference in the number of students who completed the first-term of the major's biology sequence on the first attempt based on their category of chemistry course-taking behavior ($\chi^2(3, N = 342) = 8.414, p = .04$) raises some questions about the chemistry co-requisite currently in place. The findings that students with more prior 200-level chemistry coursework tended to be more successful in their first attempt at major's biology suggests that further work should be done to investigate the possibility that chemistry should be a pre-requisite and not a co-requisite for major's biology at the study site. This pre-requisite would be consistent with the curricular scaffolding for undergraduate biology programs at other institutions (Kohn et al., 2018).

The beginning sequence of major's biology is often connected with concepts in chemistry and some undergraduate education reform efforts have focused on better integration of concepts between the physical and biological sciences (Thompson et al., 2013). Previous research on the curricular connections between undergraduate chemistry and biology has demonstrated that student experiences with some concepts fundamental to both chemistry and biology, such as energy, are presented differently between disciplines (Kohn et al. 2018). Kohn et al. (2018) suggest that instructors from different disciplines must work together to provide learning opportunities to connect concepts and facilitate transfer of knowledge. This proposal represents both a challenge and an opportunity for collaboration in a context where students are not progressing through the courses in the same sequence.

Alternatively, the increased completion for students with additional experience in college-level chemistry may reflect the filtering effect of unsuccessful chemistry as a gateway course (Cohen & Kelly, 2019a). This filtering effect may also be relevant for the patterns of course taking, and student success previously discussed for biology and math. Koch and Drake (2018) found that introductory chemistry served as a gateway course for student success. Their study of students at 36 different universities and colleges found that the average rate of not successfully completing introductory chemistry was 29% (n = 20,987). These findings were consistent with those of Cohen and Kelly (2019a) who found that enrollment in chemistry predicted a change from a STEM to a non-STEM major and concluded that chemistry was a primary STEM gatekeeper. Students who pass through one gateway course to the next one may have increased chances of success, based on characteristics related to college success that are independent of the disciplinary content they gained from the first course. Before implementing more stringent chemistry pre-requisites for the first course in the major's biology sequence a review of how critical chemistry concepts are introduced within the context of that course might also be beneficial.

Prior Physics Courswork and Outcomes

The course-taking in physics prior to attempting the first course in the major's biology sequence was very low; only 12% (n = 40) of the students in the study had college physics, at any level, on their transcripts (see Table 12). Most of that course taking was 200-level physics (9%, n = 31). Included in the 200-level physics options track were algebra-based physics and calculus-based physics. The algebra-based physics had a 100-level math requirement and the calculus-based physics had a 200-level math requirement. The need to complete these math prerequisites may have impacted the timing of physics course-taking. There was no significant difference in the number of students who completed the first-term of the major's biology sequence on their first attempt based on their category of prior physics course-taking behavior ($\chi^2(2, N = 342) = 5.97, p = .051$) (see Figure 9). Physics course-taking was not a predictor in the logistic regression model fit for transfer outcomes discussed in research question four. The low sample size for the number of students taking any physics at all precluded asking more nuanced questions based on the different physics pathways and remains an opportunity for future research. A slightly higher sample size might very well have produced a significant result, but it would nonetheless remain an uncommon element of student preparedness.

Prior Math Coursework and Outcomes

The math prerequisite for the major's biology sequence was completion of intermediate algebra, a pre-college level math class, so it is not surprising that most students (67%, n = 231) had some level of math on their community college transcript. Many students in the study had pre-college or remedial math as part of their course-taking history (42%, n = 143) but only 9% (n = 31) had pre-college math as the highest level of math on their transcript. There was a significant difference in the number of students who completed the first-term of the major's biology sequence on the first attempt based on the highest level of prior math recorded on their transcript ($\chi^2(3, N = 342) = 11.34, p = .01$). Completing college level math in the first year was identified as a variable in the logistic regression model fit for predicting transfer category for the group of students in this study (see prior discussion of research question one). This finding is consistent with earlier research identifying math as a key element in the accumulation of STEM academic momentum (Calcagno et al., 2007; Cohen & Kelly, 2019b, 2020; Hagedorn & DuBray, 2010; Park et al., 2020; Park & Ngo, 2021; Wang, Wang, et al., 2017). For example, previous research suggests that higher levels of math self-efficacy were more likely to change student academic trajectories from a vocational pathway towards a transfer degree (Chan & Wang, 2018). Many studies have documented the role of remedial or pre-college math placement in community college transfer success (Bahr, 2010, 2013a; Melguizo & Ngo, 2020; Park et al., 2020; Park & Ngo, 2021). Previous research has shown that misalignment of math placement can hinder STEM-aspiring students from pursing STEM pathways (Park et al., 2020). Practically, students in this study who were initially placed in pre-college math ($n = 143$) would not have been able to begin the major's biology sequence until they had completed that preparation; this may partially account for the low number of students in the study who attempted the major's biology sequence in their first year (30%, $n = 102$).

Course-taking patterns in math disaggregated by gender, age, race, and ethnicity are discussed in research question three. The logistic regression model fit to determine the predictive value of the number of pre-college, 100 and 200-level math credits accumulated by students in this study for transfer category is discussed in research question four. Many students in the present study had no math course-taking on their transcripts (33%, n = 111). The math prerequisite for the major's biology sequence, and the course-taking patterns examined for determination of whether they had completed college-level math in the first year, made it clear that no math on the transcripts did not mean the absence of a background in math. Students may have tested out of the math prerequisites, transferred in credits, or, had the prerequisites waived. These details would be important for establishing causal relationships and to suggest directions for future research. However, the results for this study present a picture of a broad range of math backgrounds amongst the students in the first class in major's biology. Similar to the previous discussion of chemistry concepts, attention should be paid to how biology concepts dependent on foundational math skills are presented in the major's biology classroom.

Grade Distribution and Retention

The grade distribution patterns and retention rates in the three-term major's biology sequence suggest that the first in the sequence is a gatekeeper course. Gateway courses are those that a student must complete to continue with their program of study and they can become gatekeepers that are barriers, creating friction that slows academic momentum when completion rates are low (Flanders, 2017; Hagedorn & DuBray, 2010; Zeidenberg et al., 2012). The number of students who did not successfully complete on the first attempt was highest for the first course in the major's biology sequence (29%, n = 99). Non-completion dropped considerably in the second course to 18% (*n* = 41) and again in the third course to less than 1% (*n* = 9). The high level of completion in the third class in the sequence is very encouraging but it is important to juxtapose that level of completion with the overall retention rate within the sequence of 49% (*n* = 169). Less than half of the students who begin the major's biology sequence complete it (see Table 14). It is important to note that these data reflect some students who completed the pre-requisite class but chose not to continue. Students may be taking the major's biology class for different reasons and not all educational goals would require all three terms of major's biology. Regardless, the overall picture of completion and retention in major's biology suggest that there are opportunities to improve student outcomes by focusing on the student experience at the beginning of the major's biology sequence (Brewer & Smith, 2011).

Nearly a fifth of students attempted the first course in the major's sequence multiple times (17%, *n* = 56). A few students (3%, n = 10) took the class three or more times. There were multiple attempts for the second course in the major's sequence as well (see Table 14). Of the students who repeated the first course in the sequence, 20% (*n* = 11) had a passing grade on the first attempt and only 64% (*n* =7) improved their grade on the second attempt. Only 60% of the 45 students who repeated the first class because of non-completion eventually progressed to the second course in the sequence. However, for the determined few that took the class three or more times, all of them progressed to the second course. These findings suggest that one of the additional supports that may be beneficial to this group of students is increased access to discipline specific advisors. This opportunity would be consistent with the supports suggested by the guided pathways reform movement (Bailey et al., 2015). Students registering to repeat a gateway course could be flagged for connection to advising and tutoring resources appropriate for STEM transfer pathways at the institution (Bailey et al., 2015; Packard & Jeffers, 2013).

Continuity

The students who progressed through the major's sequence in biology showed a surprising degree of continuity in their enrollment patterns. Enrollment was tracked beginning from the term they enrolled in major's biology, including summer term. Most students (82%, n = 164) who completed the first course in the major's biology sequence on the first attempt enrolled in the second class in the sequence the following term. A small number of students (9%, n = 18) waited a term and then continued to the next course. Only 4% (n = 8) waited more than a year to continue in the sequence. This pattern of course taking was consistent for the students who completed the second course in the major's biology sequence on the first attempt. Most students (86%, n = 121) took the third course in the sequence the following term. Only 3% (n = 5) waited more than a year to continue to the final course in the sequence. These results are surprising because previous research has shown that many community college students have intermittent enrollment patterns (Crosta, 2014). This previous research demonstrated a positive association between completion of a community college credential and the degree of enrollment continuity. Given this connection, Crosta (2014) expresses concern that the ability of students to begin a sequence in a flexible community college structure, at multiple points during the year rather than just in the fall, may delay success. The data presented in the current study include summer terms and represent a variety of entry points during the academic year, and suggest that continuous access to classes in the major's biology sequence is meeting a need for the students in this population. The enrollment gap between the first and second course in major's biology was not a predictor for transfer outcome as discussed in research question four. Future investigations might focus on querying those students who completed the first course in the major's biology sequence but who did not continue to the second, to see if access in terms of course scheduling details of time, place and modality of instruction was a barrier.

Enrollment Intensity

Students ranged broadly in how many credits (*M* = 11.83, *SD* = 3.57) they were taking in the term they took the first course in major's biology, most were carrying a full load while a small number were taking just the major's biology class (see Figure 13). The variation in enrollment is consistent with earlier findings by Crosta (2014) who found that community college students are extremely variable in their enrollment patterns. Enrollment intensity during the term a student first attempted the first course in the major's biology sequence was a predictor for transfer outcome as discussed in research question four.

Research Question Three

Prior Coursework in Biology, Chemistry, Physics and Math Disaggregated by Gender

Most of the students whose course-taking behaviors were tracked for this study were female (59%, n = 200). This demographic mirrors national trends for undergraduate biology in which women receive over half the bachelor's degrees awarded in the life sciences (NSB, 2019). Disaggregation of the course-taking data by gender revealed very few differences between male and female students except that fewer women were enrolled full-time compared to men. There were no significant differences between female and male students in the level of biology ($\chi^2(3, N = 337) = .56, p = .91$), chemistry ($\chi^2(3, N = 337) = .93, p = .82$), physics ($\chi^2(2, N = 337) = 1.01, p = .60$) or math ($\chi^2(2, N = 228) = .35, p = .84$) coursework completed prior to enrolling in the first course in the major's biology sequence. These results are consistent with the prior findings that, when the field of study has been controlled for, course-taking differences such as those often reported between male and female students in math, were not evident (Douglas & Salzman, 2020). Alternatively, Wang's (2016a) study on the course-taking patterns of community college students found a relationship between the number of credits of math, the timing of math, and the probability of transfer in STEM for women. No similar patterns emerged from this study. Gender was not a predictor for transfer category in the logistic regression model discussed in research question four. However, the trends that emerged when the course-taking patterns were disaggregated by gender and age, and gender, race, and ethnicity in research question three are a reminder to consider the intersectionality of identity and how that impacts student experience.

Grade Distribution Disaggregated by Gender

There were also no significant differences between female and male students in the grade distributions for the first course of major's biology ($\chi^2(3, N = 337) = 2.29, p = .51$), or for the second course ($\chi^2(3, N = 225) = 1.09, p = .78$) or the third course ($\chi^2(3, N = 167) = 1.73, p = .63$) in the sequence. These results are also consistent with other studies such as the one by Lauer et al. (2013) where there were no differences in the grades between male and female students in an introductory biology class at a mid-sized research university.

Enrollment Intensity Disaggregated by Gender

There was a significant difference ($t(335) = -2.01, p = .04$) between females and males in enrollment intensity during the term they were enrolled in their first attempt in the first course in major's level biology. Fewer females (57%) compared to males (63%) were attending full-time (see Figure 14). More females (14%) than males (9%) were just taking the major's biology class. Insight into potential reasons for this discrepancy may come from studies (Costello, 2012) that have found that community colleges have higher proportions of students who are low income and single parents (Horn & Nevill, 2006). The single parents who are attending community college are more likely to be women (Horn & Nevill, 2006). Affordability, child-care availability and tensions between work and home life can be factors that limit the ability of some women to carry high credit loads (Costello, 2012). Additional demographic and qualitative information would be needed to further explore the relationship of these potential factors to the finding that the females in this study enrolled at a lower intensity. However, it does suggest that any interpretation of course-taking behavior should take into consideration potential barriers to access such as the limited availability of evening classes for working students, or class times that do not coincide with available daycare options.

It is important to note that a small number of students in the study did not identify as female or male. The sample size was very small, so to maintain confidentiality they were removed from the data disaggregated by gender. There is a need for future research to also consider the experiences of gender non-conforming students in STEM (Kersey & Voigt, 2020).

Prior Coursework Biology, Chemistry, Physics and Math, Disaggregated by Age

Most of the students in this study were of post-traditional age (M = 26 years, SD = 6.8). Students under 18 years old were not included to exclude high school students. Students in the study were categorized into three age categories: (a) 23 years and younger (b) 24-29 years, and (c) 30 years and older. There were significant differences by age category in the level of biology ($\chi^2(6, N = 342) = 21.48, p = .002$), chemistry ($\chi^2(6, N = 342) = 20.34, p = .002$), and math ($\chi^2(4, N = 231) = 17.16, p = .002$) coursework completed prior to enrolling in the first course in the major's biology sequence, but not for physics (χ^2(4, *N* = 342) = 1.15, *p* = .87). The results may have been a function of the length of time available to older students create an educational history. This study differs from others in that all the students, 18 and older, taking the first course in the major's biology sequence were included, not just those who were first-time college students. This more inclusive group of students incorporates those returning to college to pick up prerequisite courses for professional or graduate school that included other prior 200-level STEM courses, evidenced by the finding that 55% (*n* = 5) of the students who transferred directly to professional or graduate programs were in the 24-29 years old age category. The largest portion of the students in the 24-29 years old category did not transfer directly to professional or graduate school but to a biology or biology related program (43%, *n* = 42). This trend is very similar to the portion of students in the 23 years and younger category who transferred into a biology or biology related program (40%, *n* = 63) and more than the portion of students 30 years and older who transferred into that same category (29%, *n* =24). The students aged 24-29 years were more likely to have 200-level STEM coursework compared to other age groups; with 20% (*n* = 20) of students in that group with 200-level biology, 37% (*n* = 37) with 200-level chemistry, 13% (*n* = 13) with 200-level physics and 55% (*n* = 37) with 200 level Math (see Table 18).

The possibility that the differences in amount of course-taking were strictly a function of the time available to create an educational history was not consistent with the findings for the group of students aged 30 years or more. This group of students had slightly lower percentages of 200-level biology (19%, *n* = 16), chemistry (30%, *n*

= 26), and physics (7%, *n* = 6) but much lower percentages of 200-level math (22%, *n* = 13) compared to the students in the 24-29 years old category (see Table 18). The largest portion of the students in the 30 years or more age category did not transfer (40%, *n* = 33). There is some resonance between the findings for this group of students and the complex relationship between age, credit accumulation and transfer in STEM previously explored in a study of first-time college students at community college (Wang, 2016a). Data mining techniques were used (Wang, 2016a) to determine the relationship of accumulation of STEM credits, particularly in math, and transfer outcomes. In Wang's (2016a) study students 24 years and older were found to be less likely to transfer in either a STEM or non-STEM program compared to their traditional aged counterparts when both groups had 12-25 transferable STEM credits, and 2.7-6 math credits. The discrepancies between Wang's study, and the findings for the group of students 24-29 years old in this study compared to their traditional aged counterparts, raise some questions about other important differences between age categories.

Grade Distribution Disaggregated by Age

It may be that prior educational experiences or differences in educational goals are complicating the interpretation of these results. Students who delay entry into college as first-time students often have poorer outcomes, with researcher's citing lack of study skills and competing obligations as factors (Adelman, 2006; Richardson & King, 1998). Those previous research findings are not consistent with the results of this study that there were no significant differences in the grade distributions based on age category for the first or third course in the major's biology sequence. There was a significant difference in the grade distributions based on age category for the second course in the major's biology sequence with the students in the 24 to 29 years old age category receiving higher grades compared to the younger and older students. The difference for the group of students in this study is that many of the older students have prior college experience.

Enrollment Intensity Disaggregated by Age

The role of competing obligations as factors in educational outcomes for older students is consistent with the significant differences found in enrollment intensity for students in different age groups ($F(2, 339) = 10.19$, $p < .001$), although the effect size for age was weak (*eta-squared* = .06) (Muijs, 2016). Most students who were 23 years or younger (70%) and just over half of the students who were 24 to 29 years (55%) were enrolled full-time. Less than half (44%, n = 36) of the students who were 30 years or older were enrolled full time (see Figure 15). In the group of students who were 30 years or older and attending at less than half time (usually taking just one course), most of those students were female (87%, n = 13). This was not the case for the traditional age category of students where most of the females were attending full time and they made up 61% (n = 68) of the full-time enrollment category. There is an intersection in course taking intensity of the role of age and gender, connecting to the previous discussion on the differences in course-taking intensity found based on gender. Age as a predictor for transfer outcome is discussed further in research question four. Recognizing the intersectional nature of the experiences that inform the needs of community college students is important in supporting their success. Wang et al. (2018) found that age was an important variable in determining the kind of social supports that were relevant for community college success. Female students, who are 30 or older appear to be engaging with course-taking in a different way than male or younger students and therefore may need connections to different supports and resources at the institution.

Prior Coursework in Biology, Chemistry, Physics and Math Disaggregated by Race and Ethnicity

The group of students whose course-taking behaviors were tracked for this study did not reflect the level of diversity in the general student population at the large, western community college (see Table 1). The general student body at the study site was predominately White (61%) and the group of participants in the present study was even more so, (63%). Additionally, there were more Asian students (10%) and fewer Black/African American (3%) and Hispanic students (8%) enrolled in the first course in the major's biology sequence compared to the general student population in

2014/15. This pattern of diversity in biology that is not representative of the surrounding population is consistent with the concerns for STEM engagement at the national level (Musu-Gillette et al., 2017; NSB, 2019; Valantine & Collins, 2015). Representation was equivalent to general student population for those who identified as International, Nonresident alien, Multi-racial, or Hawaiian/Pacific Islander. The representation in some of these categories of race and ethnicity was sufficiently small to require aggregation to protect student confidentiality. The aggregate category included students who identified as American Indian, Hawaiian/Pacific Islander and International/Nonresident Aliens.

There were no significant differences in credits earned prior to taking major's biology, in biology ($F(6,335) = .79$, $p = .58$), chemistry ($F(6,335) = 1.17$, $p = .32$), or math ($F(6,335) = 1.06$, $p = .39$) between students in different categories of race and ethnicity. There were significant differences seen in physics course taking ($F(6,335) = 2.3$, $p = .04$) although the overall level of physics course work was very small and the effect size was weak (*eta-squared* = .04) (Muijs, 2016).

There were some different trends in course-taking behavior between students in different categories of race and ethnicity. Most students in the American Indian and Other Races/Ethnicities, Asian, Hispanic, Non-reporting and White categories of race and ethnicity entered the first course in the major's biology sequence with no prior college-level biology coursework. Half or more of the Black/African American and Multiracial students had some prior college-level biology coursework, mostly at the 100-level (see Figure 17). Most students in all the categories of race and ethnicity except Hispanic entered the first course in the major's biology sequence with some chemistry coursework (see Figure 18). The course-taking in physics represented a very small number of students. Students in the American Indian and Other Races/Ethnicities category had the highest level of prior physics course-work and Black/African Americans had the lowest, before enrolling in the first course-in major's biology (see Figure 19). For the students with math courses on their transcript, most students in all the categories of race and ethnicity had some college-level math prior to enrolling in the first course in major's level biology (see Figure 19). More prior coursework in biology, chemistry, physics, or chemistry was not necessarily aligned with higher pass rates in the first course in the major's biology sequence.

Grade Distribution Disaggregated by Race and Ethnicity

The sample sizes for some of the categories of race and ethnicity were too small to make comparisons using inferential statistics, but some trends emerged that pointed to disparities in the distribution of grades and pass rates. Examination of the grade distributions disaggregated by race and ethnicity indicate dissimilar distribution patterns on the first attempt for all three courses in the major's biology sequence. Students who were represented in the American Indian and Other Races/Ethnicities (73%, n = 11), did not report (72%, n = 13), identified as Asian (76%, n = 25), Multiracial (68%, n = 15) or, White (74%, n = 159), completed the first course in the major's biology sequence at higher levels compared to students who identified as Black/African American (54%, n = 6), or Hispanic (52%, n = 14) (see Figure 20). Most students completed the second course in the major's biology sequence except for the Black/African American students whose pass rates dropped from 54% in the first course to 43% in the second. The pass rate for the third course in the major's biology sequence was 93% or higher for all categories of race, and ethnicity (see Figure 22). However, disaggregating the pass rates by gender, race and ethnicity indicated that the gender ratios for the remaining students had changed, and none of the Black/African American males completed the second class or enrolled in the third (see Figure 25). Slight drops in relative proportions of passing students were also seen for Asian males, who went from 42% to 31% of the passing students for that category. For all other categories, males were a higher proportion of the passing students by the third course in the major's sequence. The sample sizes were small, limiting statistical analysis. The trend observed for levels of completion for Black/African American and Hispanic students in the first major's biology course (see Figure 20) is consistent some previous studies (Hagedorn & DuBray, 2010; Weston et al., 2019). The loss of the African American males from the course sequence is also consistent with a large body of literature that documents the opportunity gap for African American males in higher education (Bush, 2010; Fries-Britt, 2017; Wood, 2012).

A comparison of the proportion of students in each category of race and ethnicity passing the first course in the major's biology sequence with and without college chemistry on their transcripts indicated higher pass rates for Asian, Hispanic, Multiracial, and White students who had prior college chemistry course work compared to no prior enrollment, but lower pass rates for students in the American Indian and Other Races/Ethnicities category and Black/African Americans who had chemistry coursework (see Figure 26). This trend is interesting because there was a significant difference in the number of students, not disaggregated by race and ethnicity, who completed the first term on their first attempt based on their category of prior chemistry course taking behavior ($\chi^2(3, N = 342) = 8.414, p = .04$), (see Figure 7). Most of the chemistry course-taking by the students in the American Indian and Other Races/Ethnicities, and Black/African American students prior to attempting the first course in the major's biology sequence was 100-level.

This finding again raises the question of the appropriateness of the existing chemistry co-requisite for the major's biology, which is a 100-level course. It is also a reminder that the level of high school preparation for students entering the major's biology sequence was unknown. The students who completed the major's biology class with no college chemistry on their transcripts may have arrived with a strong background from high school or other educational experiences (Wang, 2013a). However, since many of these students were coming in to the major's level biology sequence with college-level course work that exceeded existing prerequisite requirements and not completing, it is also an opportunity to highlight the importance of culturally-responsive and anti-racist pedagogies for the twenty-first century community college classroom because classroom climate is key factor in student success (Kishimoto, 2018; Ladson-Billings, 2014). Recent work by Whitcomb and Singh (2021), documented a ten-year trend of consistently lower GPAs for historically underrepresented students, compared to white students at a large public university for a range STEM majors, including biology. Based on their findings, these authors

(Whitcomb & Singh, 2021) call for greater support, mentoring and guidance for historically underrepresented students trying to overcome inequities faced at a primarily white institution.

Enrollment Intensity Disaggregated by Race and Ethnicity

There were no significant differences between students in different categories of race and ethnicity based on the intensity of enrollment, measured by the number of credits during the term the student was enrolled in the first course in the major's biology sequence, when compared using a one-way ANOVA ($F(6,335) = 59$, $p = .74$). Hispanic students had the highest average enrollment intensity based on credits ($M = 12.52$, $SD = 3.31$) and Black/African American students had the lowest average enrollment intensity based on credits ($M = 10.55$, $SD = 3.88$). Students in the American Indian and Other Races/Ethnicities category, and Asian students had the highest proportion of full-time attendance (see Figure 27). Black/African American students had the highest proportion of less than half-time attendance. Employment status and socioeconomic situation was unknown for these students. Enrollment intensity is an important factor in the ability to accumulate credits to achieve academic momentum (Adelman, 1999, 2006; Crosta, 2014). The majority of community college students work and the demands of work and school often present academic challenges (Horn & Nevill, 2006).

Research Question Four

Predictive Value of Course-Taking Behaviors for Transfer Outcome

The examination of leading indicators of academic momentum in research question one identified first term GPA as significant predictor of transfer outcome. Accumulation of credits associated with the biology MTM and passing college level math in the first year were found to be effect modifiers and were included in the model. The model only correctly classified 40% of cases and was a weak predictor for transfer outcomes other than transfer to a biology or biology related program. The goal of research question four was to identify variables related to course-taking that could predict transfer outcome in a multinomial logistic regression model. Based on the course-taking information gathered in research question two and the application of a purposeful selection process (Bursac et al., 2008), the following variables were fit to a logic regression model: (a) number of credits of 200-level biology accumulated prior to enrolling in the first term of major's biology, (b) the grade on the first attempt in the first term of major's biology, and (c) enrollment intensity during the term enrolled in major's biology. The model correctly classified 43% of cases and was a better predictor for all categories of transfer outcome compared to the model fit for the leading indicators of academic momentum in research question one.

Transfer to a Program that was Biology or Biology-related

The predictive value of the grade in major's biology for transferring to a program that was biology or biology related is intuitive and may be a good leading indicator of academic momentum for a biology major. Attewell et al. (2012) critique the use of student grades in Adelman's (1999, 2006) work as a measure of academic momentum because they argue it is an effect rather than a cause. The same criticism might be leveled at the use of the grade in major's biology. A counter for this argument would be the findings of Wang (2017) that STEM momentum has a cognitive domain that includes the development of STEM efficacy. Grades may not be the best measure of learning, but they are a unit of measure that is traded for resources in the academic world and they are highly valued by students. This practice has implications for advising and for targeting student support resources. The current leading indicators of academic momentum are tied to the first year of enrollment. The work of Chan and Wang (2018), suggests that a student's relationship with their goals and their community college pathway is "fluid and diverse" in their first year. The STEM momentum model suggests that students can change their direction depending on their accumulated experiences (Wang, 2016b; Wang, Lee, et al., 2017). The leading indicators for academic momentum may be more beneficial for students whose educational goals are already identified in the first year and less so for students who are exploring. Wang et al.(2019) has identified a variety of pathways that are potentially successful for transfer in STEM and some of them begin with general education courses. The addition of a predictive indicator such as the grade in the first term of major's biology would give an advisor an indicator of when a student might have begun to act on the academic goal of transferring in biology. The indicator would not necessarily be tied to the student's first year but could be easily flagged at registration with easy follow-up at the end of the term.

The predictive value for academic performance in the first term of major's biology plus the relatively high no pass rate documented in research questions two and three flag the first term major's biology class as a gateway class (Flanders, 2017; Hagedorn & DuBray, 2010). Identifying a gateway class allows for effective deployment of resources. Attention to best practices based on culturally responsive pedagogy (Ladson-Billings, 2014), embedded, accurate, discipline-specific advising (Packard & Jeffers, 2013), plus additional outreach to connect students to support systems such as information about on-campus child-care availability might help retain more historically underserved students.

Transfer to a Professional or Graduate Program

The significant predictors for transfer to a professional or graduate program included the grade in the first term of major's biology as well as enrollment intensity. In previous descriptions of elements of academic momentum, full-time enrollment has been connected to credit accumulation and successful transfer or baccalaureate degree completion (Adelman, 1999, 2006; Crosta, 2014). The negative relationship between enrollment intensity and transfer to a professional or graduate program is therefore very interesting. This finding and the somewhat anomalous age data discussed in research question three, where the 24 to 29 year-old age category of students showed very different characteristics than the younger and older cohorts is another reminder that community colleges serve a variety of functions. The group of students who are not utilizing the community college for the baccalaureate transfer function but for accumulating prerequisites to transfer to a professional or graduate program began to emerge as a distinct group in this study. The needs of this group of adult learners may need to be considered in arenas like the scheduling of classes in ways that are different from those for students accessing the community college for other reasons.

Limitations

There are several limitations in this study that must be addressed. First, this study was conducted using the transcripts from a cohort of students at a single large western community college, limiting generalizability and external validity (Muijs, 2016). Second, entering students at this institution do not currently need to declare a major, so student cohorts were identified by the proxy of course-enrollment. Student intent was inferred by enrolling in the first term of major's biology and the student may have engaged with the institution for different reasons than transfer to a four-year institution. Additional variables related to work life balance and socioeconomic status that may impact student outcomes are outside the scope of this research (Horn & Nevill, 2006). Information about educational experiences in high school or at other colleges was not available and may enhance the understanding of the patterns presented in this research (Adelman, 2006). Small sample sizes precluded inferential statistical analysis for some comparisons of data disaggregated by race and ethnicity. Therefore, emerging patterns in course-taking behavior and post-transfer outcomes will not provide inferences about causality but point to opportunities for further research (Muijs, 2016). Additionally, lack of control of the independent variables and non-random assignment of students to treatment groups are weaknesses for internal validity in an ex post facto design (Silva, 2010). The resulting limitations of the generalizability of findings when participants are not selected randomly also limit external validity (Muijs, 2016). Despite these limitations, this research has enhanced the understanding of the relationship of course-taking patterns for students at a large, western community college, in a biology transfer sequence, to transfer outcomes. There is an opportunity for future research to address the limitations and deepen the understanding of that relationship to support student success.

Future Research

The exploration of the relationship between course-taking patterns in undergraduate biology and community college transfer-success in this ex post facto study raised many questions that will help direct future research. The examination of leading indicators of academic momentum for their value as predictors of transfer outcome, for a group of students that was not limited to first-time college students and was discipline-focused, led to questions about the appropriate timing metrics. Leading indicators are usually connected to a student's first term or their first year at an institution (Belfield et al., 2019; Leinbach & Jenkins, 2008). These metrics may have limited value when a student already has a long association with an institution and if they change their goals. More research tying the development of metrics to the emergence of student educational goals is needed.

This study documented patterns of course taking using a non-experimental design. Further examination of the impact of the course taking on outcomes in major's biology including information about high school STEM experiences and any relevant International Baccalaureate or Advanced Placement transfer credit, as well as matching participants for known confounding variables, would be useful to address questions about causality. This might be particularly useful for curriculum design, including a review of appropriate prerequistes, given the relationships between prior course-taking behavior and outcomes in the major's biology sequence documented in this study.

Further research is also needed to further understand the positive relationship between prior course-taking and successful outcomes in major's biology. Characteristics related to college success that are independent of disciplinary content may include the development of greater self-efficacy (Bandura & Schunk, 1981; Lent & Brown, 2019; Wang, 2017). The STEM transfer model conceptualized by Wang (2016b) suggests that transfer momentum is gained not just by the completion of individual elements of a STEM pathway, but by the cumulative effect of a student's trajectory in that pathway. In the STEM transfer model, academic momentum is the product of ongoing learning experiences and those that student has already experienced (Wang et al., 2017). Wang suggests that a component of STEM momentum is the building of STEM efficacy as a student experiences, success in STEM courses (2017). Pragmatically, the evidence that students in the major's biology classroom may vary widely in their earlier exposure to college-level STEM coursework should challenge instructors to check assumptions about prior learning and inform the teaching strategies employed to meet student needs.

The description of course-taking behavior disaggregated by gender, age, race, and ethnicity also provided direction for further inquiry. A growing number of students are gender non-conforming (Kersey & Voigt, 2020). The small sample-size precluded bringing that perspective to this research, and more work should be done in this area to serve the needs of students who do not identify as male or female. The findings of differences in the course-taking intensity for different age groups of students raised questions about parental status, work status and socioeconomic levels. A previous study based on the 2015-16 academic year found that over 31% of community college students enrolled in the 2015-16 academic year worked full-time (AACC, 2019), so this is a key factor influencing course-taking patterns. Additional research that includes these factors would be beneficial to understanding the patterns observed. The examination of the course-taking patterns that differed based on race and ethnicity was limited by a small sample size. Future research might employ quota sampling to ensure a more diverse student sample (Muijs, 2016). Questions also arose about the experience of the students in the classroom and the role that may have played in their course taking behaviors and outcomes (Eddy et al., 2014; Riegle-Crumb et al., 2019; Seymour & Hewitt, 1997; Wood, 2012). Focus groups or other qualitative methods might be employed, in addition to quota sampling to gain a better understanding of, for example, the Black/African American male experience in major's biology. These and other student voices documenting their experiences in the major's biology classroom would be valuable to understand. the cognitive dimensions of academic momentum to further inform the STEM transfer model (Wang, 2016b).

The data used in this study represent a snapshot of the course-taking behavior and the resulting transfer outcomes for a group of students enrolled in the first course in major's biology in the 2014/15 academic year. These data may not fully represent the current situation. The issues of microaggressions in the classroom and systemic racism have begun to inform the discussion of how to support equitable student success in the classroom. The study site has more recently engaged in many discussions and a great deal of professional development to help the faculty develop skills for culturally-responsive, and anti-racist teaching practices (Kishimoto, 2018; Ladson-Billings, 2014). The data from this study period may serve as a baseline to hopefully document better outcomes at later times for historically underserved students in STEM.

Finally, the fitting of the logistic regression model with course-taking variables to predict transfer success yielded some interesting predictors based on even a small student sample. Future research could test and extend the model to improve the usefulness for informing student biology transfer advising. Refining the model to include more elements related to the timing of course taking in the major's transfer map would extend the usefulness of the findings in this study. Additionally, it would be useful to extend the generalizability of these findings by examining course-taking patterns for additional years and including additional sites from a range of geographic locations. It would be useful to know how robust the relationships found in these data were on a national level.

Implications and Conclusion

The purpose of this non-experimental, quantitative study was to investigate the relationship of course-taking patterns of community college students enrolled in a major's biology sequence to successful transfer into a biology or biology-related degree track at four-year institutions. The research was guided by the seminal work of Adelman (1999, 2006) on course-taking as it relates to academic momentum and the STEM transfer model developed by Wang (2016b). The relationship of course-taking behavior to transfer outcomes for a population of students in a biology transfer sequence at a large community college in the Western U.S. was addressed using anonymized student transcript data provided by the institution and post-community college enrollment records from the National Student Clearinghouse database.

Expand Leading Indicators of Academic Momentum

The findings of this study that inform an understanding of how students gain academic momentum for successful transfer or completion have implications for how institutional resources could be deployed to improve transfer success, decrease opportunity gaps and ultimately help diversify participation in STEM fields (Belfield et al., 2019; Jenkins & Bailey, 2017; Malcom & Feder, 2016). Most of the leading indicators for academic momentum for traditional aged, first-time community college students (Adelman, 1999, 2005; Belfield et al., 2016, 2019; Calcagno et al., 2007; Chan & Wang, 2018; Clovis & Chang, 2019; Hagedorn & DuBray, 2010; Leinbach & Jenkins, 2008) were not good predictors of transfer outcomes for the more heterogenous group of students in this study. Seven metrics were investigated and of those only first-term GPA was significant predictor of transfer outcome for this population. Two additional variables were identified as effects modifiers: program credits completed the first year and college math completed the first year. This confirms the predictive value of a few of the leading indicators of academic momentum but suggests that as signposts for focusing institutional resources in support of the student population studied, these indicators are not entirely adequate.

Focus on the Classroom Experience

Course-taking behaviors for a group of students in a biology major's sequence were documented to gain a better understanding of academic momentum in this population to identify more relevant leading indicators. The description of course-taking behavior for students prior to enrolling in the first-term of major's biology indicated a broad range of preparation in college-level biology, chemistry, physics and math. Wang's (2016b) STEM transfer model includes aspects of the students' experiences in the classroom in the theoretical framework. These elements combine the details of student course-taking behavior that creates STEM specific momentum (Wang, 2015) that in turn affects self-efficacy in STEM and outcome expectations regarding STEM and STEM transfer. This study informs that framework with the discipline and institutional specific details of how students are entering the major's biology sequence. The broad range of prior college-level coursework of students in major's biology suggests the need to focus on that classroom experience. Prior research has explored the need for additional support for students coming into the college STEM classroom with deficits in their high school background (Carver et al., 2017; Xu et al., 2018). The findings in the current study shift that conversation to consideration of the classroom climate when students are coming in with a wide range of assets based on their college-level background. In their seminal work, Seymour and

Hewitt (1997) discuss the role of an unwelcoming classroom climate as a factor for students leaving STEM classrooms. More recent work suggests that in many areas this has not changed, and undergraduates still experience the STEM classroom culture as competitive and unsupportive (Hunter, 2019). The reality of a student population with a very broad range of experience and STEM skills may exacerbate existing inequities and create an even more challenging classroom environment. Changing the classroom environment will require the instructor to intentionally create a supportive learning culture.

Support Quality Instruction

Creating a supportive learning culture that supports students with a broad range of STEM experience requires high quality instruction. The quality of instruction has been recognized as a key component in the success of undergraduate STEM students, particularly for historically underserved students (Brewer & Smith, 2011; Graham et al., 2013). While pedagogical differences exist between STEM disciplines (Fairweather & Paulson, 2008; Singer et al., 2012), teaching strategies that incorporate elements of active and collaborative learning have been found to improve student outcomes across STEM disciplines, particularly for historically underserved student populations (Fairweather & Paulson, 2008; Freeman et al., 2014; Haak et al., 2011). Quality instruction is not just a function of strategies but also of an understanding of the learning process. Andrews et al. (2011) found no association between success and changes in instructional practices such as the incorporation of strategies like active learning. They suggested that an understanding of the underlying pedagogy was important in how effective the active learning strategy was in the classroom. This is consistent with the assertions of D'Avanzo (2013) that change in undergraduate STEM teaching is limited by a lack of understanding of theory both for practice and for models of change. Schinske et al. (2017) suggests a number of strategies specific to the community college for connecting theory and practice through broadening participation in biology education research. Additionally, productive partnerships between education and STEM departments at the undergraduate level are beginning to emerge, such as that documented by Schneider and Pickett (2006) for engineering and these may provide a model to support changes in classroom culture in major's biology.

The focus on reform in the biology classroom experience is not new (Brewer & Smith, 2011; Henderson et al., 2011). Despite national investments in major reform initiatives and a large body of research documenting best practices in undergraduate STEM teaching, change in teaching strategies in undergraduate STEM classrooms has been slow (Dancy & Henderson, 2008; Singer et al., 2012; Stains et al., 2018). Barriers to STEM faculty changing teaching strategies include institutional and individual variables including, time, mismatch of institutional support and rewards systems, lack of pedagogical training, student resistance, and professional identity (Brownell & Tanner, 2012; Henderson et al., 2011). These realities and the documentation of the range of student preparation in the major's biology class implies that an institutional commitment to professional development is needed to support both full-time and part-time instructors to develop the skills to create a classroom environment supportive of adult learners in the biology major's sequence.

Focus on Equity and Inclusion

The results of this study documented differences in course-taking patterns of the adult learners in the major's biology sequence based on gender, age, race, and ethnicity. The trends identified suggest a need to consider the intersectionality of student identities and tailor supports to meet those needs. Strategies to meet those needs might include connecting students to advising or student services resources, as well initiatives to evaluate the classroom climate for equity and inclusion (Bailey et al., 2015; Goldrick-Rab & Shaw, 2018; Packard & Jeffers, 2013; Whitcomb & Singh, 2021).

It is important to note that the categories of race and ethnicity used in this study were based on how the students self-identified using the categories provided at the time of enrollment. These categories do not adequately represent the variation in student identities and experiences. Mindful of these limitations there is a need to engage student voices. To create a student-centered culture where the focus is on meeting the needs of a diverse group, who are engaging with the institution in a variety of ways for different reasons, the students need to be part of the process to further understand implications of the differences in course-taking patterns documented in this study.

Discipline-specific Leading Indicators of Academic Momentum

The course-taking patterns examined in this study that were fit to a logistic regression model identified a potential new leading indicator of academic momentum for a heterogenous group of students in a biology transfer sequence. The grade in the first course of the major's biology sequence was a signficant predictor of transfer to a biology related program. This information combined with the findings based on the logistic regression model fit for leading indicators of academic momentum (Adelman, 1999, 2005; Belfield et al., 2016, 2019; Calcagno et al., 2007; Chan & Wang, 2018; Clovis & Chang, 2019; Hagedorn & DuBray, 2010; Leinbach & Jenkins, 2008) where first term GPA was also signficant predictor of transfer for the overall model, begins to tell a cohesive story of the importance of early achievement. This is consistent with the STEM transfer model (Wang, 2016b) where the trajectory of the student is influenced both by the accumulation of appropriate academic elements, like gateway courses and the development of self-efficacy and outcome expectations (Lent et al., 1994; Wang, 2016b). The combination of these early leading indicators, one general and one very discipline specific predictor, can help focus institutional resources to better support student outcomes.

Conclusion

The overall completion rate for the major's biology class was low, suggesting that this is an important gateway class. The results of this study suggest a number of opportunities for institutional support. The relationship of prior coursetaking and outcomes, especially for chemistry and math, suggest a review of the prerequisites would be beneficial, and informs advising for program pathways. The number of students taking the course multiple times suggest an opportunity for targeted advising and embedded connections with student services supports. The broad range of STEM background and varying levels of enrollment intensity combined with the low completion rates for some historically underrepresented groups suggest that appropriate professional development to prepare instructors to support students more holistically is warranted. This study reflects the course-taking and outcome patterns of students at a particular point in time and may provide a baseline for assessing the success of reform initiatives the institution has since embraced. The landscape of the community college classroom is complex and this study documents some of the complexity of the major’s biology classroom at a community college. The mission of a community college is to serve the community. Understanding the community of biology STEM learners better is a key step towards fulfilling that mission.

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