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A Novel Research Design: Using Multilevel Discrete-Time Survival Analysis to Investigate the Effect of Calculus I on Engineering Student Persistence

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Abstract

The persistence of engineering students through graduation continues to be a concern in higher education. Previous studies have highlighted a link between students' performance in introductory mathematics courses and graduation rates. Focusing on a crucial foundational course within the engineering curriculum, the purpose of this study is to investigate how students' performance in Calculus I impact their persistence in the engineering and to do so in a way that is more robust than a single-institution study. Utilizing data from 22 diverse educational institutions using Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD), this study employs multilevel discrete-time survival analysis to investigates the longitudinal patterns of persistence, considering the hierarchical nature of students within institutions. This paper seeks to devise a study design investigate the relationship between Calculus I performance and student persistence in engineering programs, employing a methodological approach that considers the hierarchical structure of student data across institutions. This study aims to fill this gap by proposing a multilevel discrete-time survival analysis, a methodological approach that offers a nuanced understanding of persistence patterns over time. Discrete-time analysis is an event-based approach that has the advantage of analyzing time in discrete chunks during which the event of interest could occur. The technique is a type of survival analysis, which has been used in studies in engineering education and other educational studies. This approach addresses challenges that may arise due to censored observations – observations for whom their entire educational pathway is not yet known because they are still enrolled. Using a multilevel form of this analysis approach also accounts for the hierarchical nature of the data involving students nested within institutions and incorporating variables that change over time. The paper primarily focuses on presenting the theoretical framework and proposed methods; it does not include results or analysis to avoid publishing results that may change based on peer review of the research design. Future findings are expected to have implications for advising strategies and institutional policies aimed at improving student retention in engineering programs. Thus, the study takes into account the variability and complexities inherent in the analysis of different institutions and examines persistence patterns more comprehensively than previous studies. By incorporating a diverse range of institutions, the study captures a broader spectrum of experiences and contexts, which enhances the generalizability of the results.

Keywords: Calculus I, engineering education, student persistence, multilevel analysis, diversity, higher education.

Introduction

Examining retention enables institutions to identify various factors that influence student persistence, such as understanding why some high-performing students choose not to return to the university [1]. Student departure, as highlighted by researchers like Aljohani [2], significantly affects educational success indicators; however, institutions have struggled to effectively address this challenge.

The retention rate of an institution plays a pivotal role in influencing various aspects such as student recruitment, funding allocation, and public perception [3]. It is crucial for a university to investigate retention to understand the reasons behind student departures. Retention rates among college students are frequently employed as a metric for gauging institutional accountability and success. Moreover, these rates are increasingly utilized as a basis for allocating resources.

Gaining insights into the factors that influence college student retention has become imperative for institutions of higher education. The ongoing issue of low graduation rates among students in engineering programs remains a significant cause for concern within the higher education landscape. Many students drop out early in their undergraduate studies. About half of students entering engineering programs successfully complete their degrees [2]. A modest percentage, less than 20%, manages to complete their engineering degrees within four years, with fewer than half doing so within six years [4]. This concern over persistence in engineering programs has prompted numerous researchers to explore the factors influencing students' persistence and decisions to change their majors. Although various factors have been documented as potentially associated with students' graduation in engineering [5], understanding these influences remains a complex and critical area of investigation. A significant factor contributing to students leaving engineering is often associated with the coursework required of engineering students early in their academic journey [6].

Studies have highlighted the critical role of the initial mathematics course within an engineering program [7] and the corresponding grade achieved in predicting the likelihood of graduating with an engineering degree [8]. This study builds upon prior research that explored the relationship between mathematics courses and grades, particularly focusing on Calculus I. However, it advances the understanding by encompassing data from multiple institutions. This broader scope enhances the generalizability of the results, providing a more comprehensive and robust analysis across diverse educational settings. The purpose of publishing this paper is to subject the methods to rigorous peer review before finalizing results. Peer review ensures that the methods used are robust and unbiased, mitigating the risk of drawing conclusions from potentially biased methodologies. While the paper primarily focuses on presenting the methodology and theoretical framework, the outcomes of this investigation are expected to carry potential implications for various aspects, including advising strategies and institutional policies aimed at improving student retention in engineering programs.

The student retention rate refers to the proportion of students who successfully complete a semester at a higher education institution and then return for the subsequent semester. This metric not only bears significance for the university itself but also extends its impact to the surrounding communities where higher education institutions are located [3]. Understanding persistence continues to be a national priority, influencing the need to increase the number of engineering graduates.

Purpose of Study

This research employs multilevel discrete-time survival analysis to investigate the impact of Calculus I performance on student persistence in Engineering programs. The study pioneers the integration of multilevel and discrete-time survival analysis, providing a novel approach to model the influence of Calculus I on students' persistence to completing their degrees.

The analysis is designed to consider a comprehensive range of student- and institutional-level covariates, ensuring a thorough exploration of factors influencing persistence. Notably, the study takes into account variables that are both time-invariant and time-varying, offering a nuanced understanding of the dynamics involved. Survival analysis emerges as a suitable method for exploring persistence to graduation, offering the capability to consider longitudinal patterns at various time points. This method enriches the understanding of both students who leave within a specific enrollment period and those who continue beyond it. Moreover, survival analysis allows for the analysis of variables in a time-sensitive manner, providing valuable insights into the evolving nature of student persistence.

The application of multilevel modeling in this study addresses the hierarchical nature of multi-institutional data. This approach contributes to more robust parameter estimates compared to conventional regression models, ensuring a nuanced understanding of the interplay between Calculus I performance and student persistence in Engineering programs.

Significance of the research

This work adds to the literature of student persistence in higher education particularly in Engineering as by examining not only individual variables at student level but also additional levels, with a particular focus on the institutional hierarchy. There have been limited investigations utilizing discrete hazard models to explore retention in higher education, with fewer examining the hierarchical aspects of student retention in Engineering. While existing studies [7, 9, 10] have explored the relationship between introductory mathematics courses and engineering student persistence, there is a notable gap in the literature regarding a comprehensive, multilevel analysis that incorporates diverse institutions. Prior studies lack the depth required to understand the factors influencing student retention through the specific lens of Calculus I thoroughly.

This research aims to fill these gaps by providing a more nuanced examination of the role of Calculus I in engineering student persistence. It incorporates a diverse range of 22 educational institutions, allowing for a comprehensive understanding of how the impact of Calculus I varies across different types of institutions, including those with varying sizes, locations, and demographics. Moreover, the study addresses the challenges associated with censored observations, employing multilevel discrete-time survival analysis to handle incomplete pathways and provide a clearer understanding of the factors influencing outcomes. This approach ensures a more robust examination of student persistence, emphasizing the unique contribution this research makes to the existing body of knowledge.

We were not able to identify the use of multilevel discrete-time hazard models in engineering education research, much less studies of that sort investigating the influence of Calculus I on the student outcomes.

Research Questions

To achieve a thorough understanding, the study seeks answers to the following research questions:

1. How does the performance of engineering students in Calculus I influence their persistence in the engineering program across diverse educational institutions?
2. Are there significant differences in the persistence patterns of students in engineering programs based on their performance in Calculus I, considering variations in institutional characteristics?
3. How does the effect of Calculus I on engineering student persistence evolve over time, and are there critical periods or populations where the impact is more pronounced?
4. How do institutional characteristics moderate the relationship between Calculus I performance and engineering student persistence?

Literature Review

This review of literature starts by introducing the broader topic of college student persistence and subsequently narrows its focus to examine the specific influence of Calculus I on the persistence of engineering students.

Persistence is important to institutions as well as students

The persistence of students in higher education bears considerable significance, underscored by national statistics. According to data from the National Center of Education Statistics in 2020, around 60 percent of full-time college students at four-year institutions graduate withing six years [11]. This statistic lays the groundwork for understanding the challenges associated with guiding students successfully through their academic trajectories. Beyond academic success, student retention is a critical factor in cultivating a diverse, skilled, and adaptable engineering workforce [12]. The ability of institutions to navigate these challenges and support students through to graduation directly impacts the vitality and innovation of the engineering profession [13]. Sustaining student retention extends beyond mere academic achievement; it stands as a pivotal factor in fostering a diverse, skilled, and adaptable engineering workforce [12]. From its origins in the industrial revolution to the contemporary era of digital transformation, engineering programs have played a crucial role in shaping the innovators and problem solvers of the future [14]. As the field has advanced in complexity, so too has the significance of ensuring the persistence of students throughout their educational journey [15]. Given that policymakers heavily rely on student retention and graduation rates to assess the effectiveness of higher education institutions [16, 17], it becomes imperative to grasp the factors influencing college persistence. This understanding forms a critical foundation for shaping policies and developing programs aimed at enhancing college graduation rates [18].

Research on persistence in Engineering Education

Various pre-college characteristics tied to persistence in engineering often revolve around robust performance in mathematics, particularly on standardized test scores. An analysis of undergraduate engineering students' survival rates [19] revealed a significant correlation between higher SAT mathematics scores and persistence in engineering. SAT math score and high school GPA seem to be common predictors of persistence [20]. Other studies have associated various demographic factors with persistence, including gender, race/ethnicity, and citizenship [21], but where those studies were multi-institution, the findings varied among institutions [20].

Understanding today's engineering education necessitates addressing the challenges students face once they begin their studies, and researchers have studied how various academic factors in the undergraduate years (course grades, overall GPA, etc.) relate to student retention in engineering [22-26]. Another investigation assessed the correlation between freshman year retention in an engineering program and basic aptitude and affective factors. Aptitude, gauged through SAT scores and calculus readiness, showed a significant association with engineering student retention, acknowledging limitations in generalizability due to program distinctiveness [27]. The goal of this research is generally to help shape educational practices and policies that support students, ensuring future engineers are both high-quality and diverse [28].

The landscape of engineering education has undergone significant transformations over time, mirroring the dynamic progress in technology and the evolving requirements of the global workforce [29]. The use of many years of data in this study both allows research that averages over all those changes and also has the potential to look for trends over time.

The relationship between early mathematics performance and engineering success

The relationship between early mathematics performance and engineering success is multifaceted. One study found that success in introductory mathematics courses, particularly Calculus I or advanced courses, correlates with higher rates of engineering degree completion [30]. However, when considering both grades and course levels, students excelling in lower-level math courses show comparable graduation rates to those struggling in higher-level math courses, highlighting the complex interplay between mathematics proficiency and persistence in engineering [30].

The current body of literature addressing the intersection of math readiness and the persistence and success of engineering students primarily relies on single-institution studies, typically recognizing their inherent limitations in universal applicability. This literature segment delves into studies examining the intricate association between math readiness and retention in engineering, emphasizing the critical perspective of studies conscientiously articulating the limitations of their findings rooted in single-institution datasets. This approach ensures a nuanced understanding of the link between math readiness and engineering student persistence while considering contextual constraints.

Whereas some studies assert that most students leaving the engineering field do so before completing challenging courses [31], other research shows that the early math and science classes, including Calculus I, pose significant challenges [32]. Within most engineering programs, Calculus I is required and frequently acts as a gateway to more advanced courses, contributing to the departure of students from engineering programs. In a longitudinal study involving over 35,000 pre-engineering students, it was found that 84% of those who departed from engineering did so before completing their pre-professional curriculum of courses such as Calculus and Physics [22]. Data indicate that proficiency in key foundational areas is crucial for engineering success. Several studies explore the relationship between students' initial math courses, grades received, and their persistence in engineering programs. Noteworthy is a study [33] focusing on first-year engineering majors, indicating that commencing with calculus as the first math course doubled the likelihood of persisting in engineering compared to starting below calculus. Moreover, those earning A/B grades demonstrated a 6.5 times higher likelihood of persistence. However, the study cautiously acknowledged potential limitations in generalizability.

The role of mathematics proficiency has been suggested as a key factor affecting persistence in the science, technology, engineering, and mathematics (STEM) fields, with particular emphasis on engineering [34]. Performance in courses that serve as a prerequisite to many other courses – called variously barrier courses, gateway courses, and other terms – is a critical factor influencing a student's persistence in the field of engineering, leading some students to doubt their capability to successfully complete the degree [23]. In engineering, Calculus seems to be a primary obstacle, identified as a significant factor contributing to student attrition [35]. Individuals who attain a C average or lower in Calculus demonstrate a higher likelihood of exiting engineering programs [24, 26]. Notably, not all engineering students who persist necessarily achieve high academic grades. Success in subsequent courses, particularly those building upon Calculus, is significantly influenced by performance in Calculus itself [31]. Overcoming the challenges posed by Calculus-based Physics is crucial for attaining success in an engineering program.

While early academic momentum strongly influences students' eventual degree completion [36], departures from the engineering field are not solely attributed to academic challenges; a considerable proportion of students exit while maintaining good academic performance [20]. The research by Chasmar et al. [9] indicate that the grade obtained in the initial college-level mathematics course significantly predicts persistence in engineering, whereas the actual starting level of the mathematics course did not play a significant role. Moreover, Baisley and Adams [37] emphasize the critical role of Calculus I performance in forecasting engineering student persistence. They found that students who persist typically achieve a B grade in Calculus I, contrasting with those who leave the program, averaging a C+. Additionally, their study establishes the Calculus I grade as the foremost predictor of persistence in engineering, with each letter grade increase correlating with a 1.88 to 2.1 times higher likelihood of persistence or graduation. Furthermore, the study conducted by Tsui and Khan [38] underscores the dual role of mathematics in engineering education. It not only acts as a significant barrier to completing an engineering degree but also correlates with better performance in engineering courses. Their research highlights the importance of mathematics proficiency, especially in high school and first-year undergraduate mathematics units, in shaping students' success in engineering programs.

Conflicting results in the study of factors predicting persistence

As noted earlier, numerous studies have diligently examined factors influencing the retention and success of engineering students [20, 21]. Despite the wealth of research in this area, a consensus remains elusive, as studies often diverge in their findings. Notably, the influence of gender has been a subject of contention, with some studies asserting its significance [21], while others dispute its impact [20]. Similarly, academic factors, such as high school GPA, have been identified as influential in some investigations but not in others [20]. The discordance in findings underscores the complexity of these variables and necessitates a nuanced examination within specific local contexts and settings. Recognizing the intricacies of such factors at a micro level is crucial for a comprehensive understanding of their role in engineering student persistence.

Among the most likely explanations for the inconsistent and at times conflicting results found in the literature is the role that institutional context plays in student outcomes. Many of the researchers cited acknowledge this limitation in their work. Hayden found that the impact of first-year experiences on students revealed varied based on pre-college levels of organizational and learning skills, yet acknowledged that the study was conducted within a specific context and centered around a particular group of students, and thus provided valuable insights while also highlighting potential limitations in generalizing its findings to broader institutional settings [39]. The specificity of the study population and contextual focus underscores the importance of considering the unique characteristics of individual institutions when interpreting and applying the results. While offering valuable insights into the relationship between first-year experiences and pre-college skills, it prompts a careful consideration of the broader applicability of these findings to diverse educational environments.

The findings from a study in a community college in southeastern Pennsylvania showed that the determinants of female students' persistence in a STEM program are not necessarily going to generalize to the nation's flagship institutions because of the many institutional differences present – community colleges not only have different organizational structures, but also enroll students who are different from those beginning their studies at four-year institutions in many ways [40]. This does not entirely discount the value of single-institution studies, however. A study [41] conducted at Louisiana Tech University explored the impact of background knowledge on the success of freshman engineering students, as measured by grades and graduation rates. The author acknowledges the limitation of analyzing data from a single university, and also notes that the focused examination of a specific context provided a nuanced understanding that might be obscured by institutional variation.

Collectively, these studies underscore the potential benefit of a nuanced approach that considers institutional differences in the context of a multi-institutional study that will generalize result to a broader educational landscape.

The measurement of persistence

The decision to control for student and institutional differences in multi-institution studies is a crucial consideration, and various tools are employed to navigate this complexity. Instruments like the College Persistence Questionnaire (CPQ), National Survey of Student Engagement (NSSE), and the Multiple-Institution Database for Investigating Engineering Development (MIDFIELD) offer diverse perspectives on student experiences [42]. MIDFIELD, specifically designed for cross-institutional research, features multi-institutional datasets that are meticulously adjusted to a common format, minimizing the disparities associated with differences in data definitions [43].

Although a commonly used measure of success in engineering is eight-semester persistence, as highlighted in several studies by [44-47], later research using MIDFIELD revealed a systematic majority measurement bias associated with that metric [48], suggesting that a six-year graduation metric is more appropriate. Many scholars investigating undergraduate persistence have employed six-year graduation rates as a metric [49-51]. This timeframe, established as a standard by the Integrated Postsecondary Education Data System (IPEDS), corresponds to 150% of the expected time to graduation [11].

As common as the six-year graduation metric is, within the discipline of engineering education, the assessment of student persistence unfolds across varied timeframes. Short-term evaluations predominantly center on the transition from the inaugural to the subsequent academic year, as exemplified by studies tracking students' progression from the first to the second year of engineering [52]. The persistence of engineering students in the initial years holds significant importance as a substantial majority of those who discontinue their studies tend to do so within the first three semesters [19].

Diversity of institutions

This section delves into the crucial consideration of the diverse landscape of institutions in studies focused on engineering student persistence. Recognizing the distinctive characteristics of various educational settings is essential for achieving a comprehensive understanding of the factors influencing student outcomes. Engineering education takes place within a diverse array of institutions, each characterized by its distinct culture, policies, and student demographics. Understanding the intricate dynamics of student persistence requires a thorough exploration of the diversity that exists among these institutions.

While single-institution studies are valuable in specific contexts, they fall short in capturing the breadth of experiences across the spectrum of engineering programs. The shift toward multi-institutional studies, exemplified by the application of databases like MIDFIELD, provides a more encompassing view. This approach allows researchers to unravel patterns and trends that may be specific to certain institutional types or prevalent across diverse settings. The persistence landscape in engineering is inherently tied to the characteristics of individual campuses. Ohland et al. [46] note that persistence differs significantly between institutions due to factors such as campus culture, policies, and institutional selectivity [53]. These differences can arise due to the cultural fabric of an institution [54] and policy differences [55] in addition to differences in their student populations [2, 56]. Understanding these nuances is pivotal for a comprehensive analysis of engineering student outcomes.

In summary, the diversity of institutions shapes the landscape in which engineering students persist. Acknowledging the variations in culture, policy, and selectivity is pivotal for an in-depth analysis. The use of multi-institutional datasets emerges as a strategic approach, allowing researchers to uncover patterns that transcend individual campuses while accounting for those differences, contributing to a more robust and broadly applicable understanding of engineering student persistence.

Theoretical Framework

Tinto's Theory of Student Departure

The exploration of student retention theories in higher education commenced in the 1970s. In 1975, Tinto [57] introduced a model of student departure, as depicted in Figure 1. This model predominantly draws on Spady's notions of academic and social connections between students and their institutions. Tinto also incorporates Durkheim's suicide theory (1961), which attributes an individual's lack of social and intellectual integration in society to suicide [58]. Tinto [59] argues that similarities exist between dropping out and suicide processes, both involving voluntary withdrawal from a specific society.

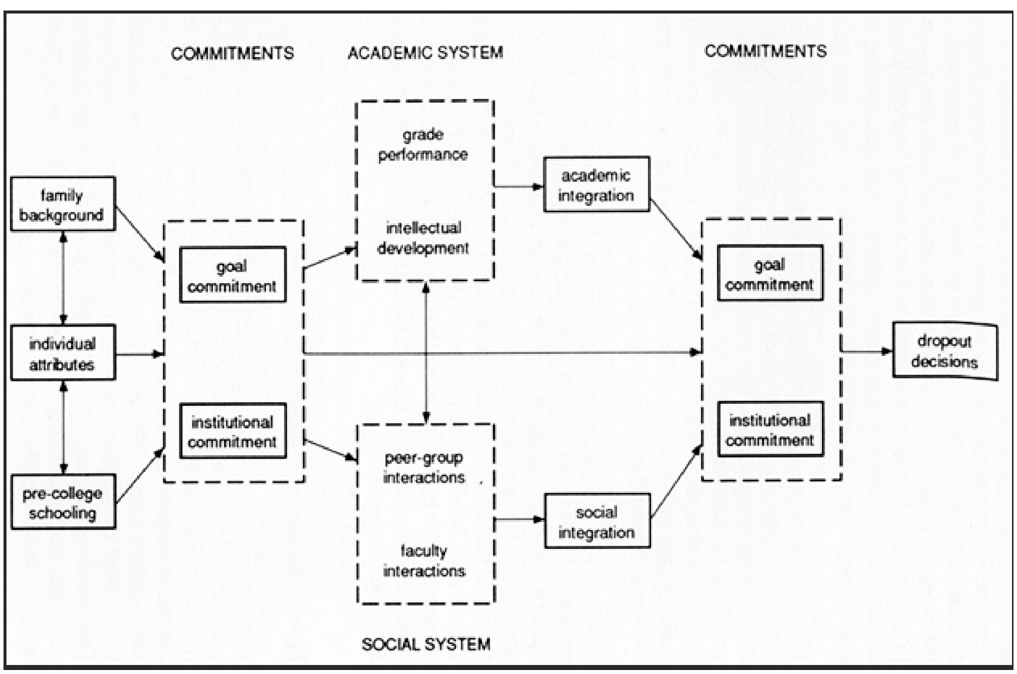

Figure 1. Tinto's model of Institutional Departure [57].

Tinto's "Model of Institutional Departure" posits that "students need integration into both formal (academic performance) and informal (faculty/staff interactions) academic systems, as well as formal (extracurricular activities) and informal (peer-group interactions) social systems" [59].

The model delineates educational institutions into two systems: academic and social, with the aim of fostering positive academic and social interactions throughout students' higher education experience. Tinto asserts that student retention is not a random occurrence; it can be predicted based on the attribution of academic and social interactions. The model emphasizes that a student's experiences academically and socially with an institution influence their commitment level, directly predicting retention. Figure 1 illustrates the significance of academic and social integration in the model. Tinto contends that varying levels of integration contribute to a student's decision to drop out. The model proposes that intentionally designing social and curriculum integration throughout students' college experiences positively influences retention. Social integration is measured through interactions with peers, institutional personnel, and faculty members, while academic integration is gauged through grade performance and intellectual development. The interplay between academic and social integration influences the decision to drop out or persist. Tinto's model also posits that students' initial goals, shaped by pre-entry attributes, are modified by their experiences at college, subsequently influencing the decision to drop out or persist. However, Tinto argues that external commitments, such as family, affect both initial and modified levels of commitment [57].

Tinto identifies four types of dropouts: permanent, temporary, voluntary, and involuntary. Permanent dropout occurs when a student decides to drop out and not return. Temporary dropout happens when a student leaves higher education temporarily, often due to transitions like transferring to another institution. Voluntary dropout results from non-academic factors, such as low commitment, while involuntary dropout is due to academic failures [60]. Tinto underscores that the choice of curriculum not only shapes learning but also influences persistence. When academic and social norms are highly satisfied, persistence naturally arises, particularly crucial in a student's freshman year [61].

Numerous studies have tested and applied Tinto's model across different institutional settings, revealing its predictive validity. The correlation between social and academic integration and persistence has been consistently observed. Tinto's model has long served as a guide for exploring factors impacting student persistence and predicting those at risk of dropping out [62]. Inspired by Tinto's model, cohort-based learning strategies have been implemented in community colleges, contributing to both social and academic integration within and outside the classroom [63]. Scott-Clayton suggests that programs structured to prevent individual deviations are more likely to promote persistence and success. Tinto's theory is valuable for comprehending the factors influencing the overall student experience in college.

Criticism of Tinto's Theory of Student Departure

Although Tinto's theory has significantly contributed to the study of persistence, some scholars have raised Concerns regarding its relevance to non-traditional students, such as racial minorities

[64]. While acknowledging these criticisms, our research design accounts for these limitations. By adopting Astin's Input-Environment-Output model, we aim to provide understanding of the factors influencing engineering student persistence. This comprehensive approach allows us to navigate potential shortcomings and enrich our exploration of the interaction between academic experiences and institutional environment in the context of engineering education.

Astin's Input-Environment-Output Model

Astin's (1993) Input-Environment-Output (I-E-O) conceptual model forms a foundational framework for understanding student development in the college environment [65]. This model posits that the process of student development unfolds longitudinally and is shaped by two key components: input and environment. The input component encompasses students' background characteristics and pre-college experiences, representing the foundational elements they bring to their college journey. On the other hand, the environment component encapsulates the experiences students encounter within the college setting and the broader institutional context in which they are situated. The I-E-O model serves as a lens through which researchers can examine the profound impact of students' college experiences on their overall development [66]. This conceptualization is suitable for our study as we navigate the influence of Calculus I on engineering student persistence, aligning with Astin's model to understand how academic inputs and the college environment shape students' outcomes over time.

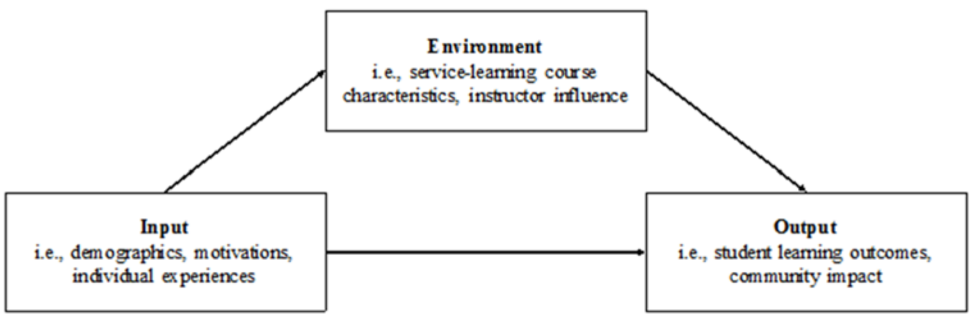

Figure 2. Astin's I-E-O Model [65].

Integrated Perspective for Research

In this study, we therefore adopt an integrated theoretical framework drawing on Tinto's Theory of Student Departure [57, 59] and Astin's Input-Environment-Output (I-E-O) model [65] to enrich our exploration of the academic integration of Calculus I and its impact on engineering student persistence across multiple institutions.

Tinto's Theory of Student Departure provides a foundational lens through which to understand the intricate dynamics of academic and social integration. Tinto emphasizes the pivotal roles of both formal (academic performance) and informal (faculty/staff interactions) academic systems, as well as formal (extracurricular activities) and informal (peer-group interactions) social systems. The model underscores that student retention is not random but can be predicted based on the attribution of academic and social interactions. Our study aligns with Tinto's emphasis on academic factors by investigating how engineering students navigate and perform in Calculus I, a fundamental course in engineering education.

Social integration, as conceptualized within Tinto's Theory of Student Departure, is a critical aspect of student persistence that extends beyond individual interactions to encompass the broader institutional context. The effectiveness of social integration is linked to the dynamics within the educational environment. Institutional context shapes the nature and availability of social opportunities, influencing how students engage with their peers, faculty, and the broader campus community.

Within the diverse landscape of higher education institutions, variations in institutional size, culture, and mission can significantly impact the social integration experiences of students. Larger institutions may offer a wider array of social activities and resources, potentially fostering diverse social networks. In contrast, smaller institutions may provide a more close-knit community where social interactions are characterized by familiarity and personal connections. Additionally, the institutional commitment to fostering inclusivity and diversity plays a crucial role in shaping the social fabric.

Moreover, the nature of extracurricular activities, support services, and community-building initiatives within the institutional context can profoundly influence the social integration of students. Institutions with robust mentorship programs, collaborative learning environments, and inclusive social events may enhance the quality of social integration, creating an environment where students feel a sense of belonging and connectedness.

The socio-cultural environment within an institution, including its norms, values, and overall climate, also contributes to the social integration of students. Institutions that prioritize a supportive and inclusive culture are more likely to facilitate positive social interactions, reducing the risk of social isolation and fostering a sense of community.

In examining the connection between social integration and institutional context, our study recognizes the dynamic interaction between individual experiences and the broader institutional environment. Thus, social integration, situated within the unique characteristics of each institution, might contribute to the persistence of engineering students undertaking Calculus I. This approach allows us to explore not only the micro-level interactions but also the macro-level institutional dynamics that shape the social integration experiences crucial for student success and retention.

Additionally, we integrate Astin's I-E-O model to structure our exploration of the broader institutional environment. The I-E-O model posits that the development of students during their college experience occurs longitudinally and is influenced by both student inputs (background characteristics and pre-college experiences) and the college environment. This integrated approach allows us to categorize research into distinct components, including student's background personal characteristics, pre-college learning experience, institutional environment and experience. Astin's theory of academic involvement within this framework further contributes insights into the multifaceted factors that shape student development over time.

By leveraging both theoretical perspectives, we aim to provide a comprehensive understanding of the academic integration of Calculus I and its influence on engineering student persistence. Tinto's focus on the interplay between academic and social integration enriches our examination of student commitment, while Astin's structured framework assists in organizing the literature and considering the broader institutional context. This integrated theoretical framework ensures a nuanced exploration of factors influencing engineering student persistence, capturing the complexity of interactions from the academic to the institutional level.

Methods

Data source

The primary source of data used this study is the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) [43]. Compiled in a common format to accommodate cross-institutional research, MIDFIELD comprises whole-population data for degree-seeking undergraduate students for approximately 22 institutions, all of which have ABET-EAC-accredited engineering programs, although data for students of all majors have been collected. It encompasses detailed records for each student, including academic metrics (SAT scores, college courses, choice of major) and demographic information (sex, race/ethnicity, etc.). MIDFIELD's data consists of a diverse representation of institutions [67]. This diversity ensures balanced regional and institutional variations. Given that regional context and institutional control influence the student experience [68], MIDFIELD enhances the potential for findings to be representative of U.S. engineering students [70].

Figure 3. MIDFIELD institutions map [67]

The MIDFIELD dataset and its use

MIDFIELD encompasses whole-population data for the participating institutions and years available, rendering significance tests unnecessary for reporting descriptive statistics [43]. Nevertheless, caution is warranted in generalizing findings to institutions not represented in the dataset [70]. In an effort to evaluate the generalizability of MIDFIELD, it was found to be representative of a broader national dataset to the extent that the two datasets could be compared [69]. The utilization of the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) in various studies demonstrates researchers' concerted efforts to navigate the challenges posed by institutional and student differences.

The substantial size of MIDFIELD allows for detailed disaggregated analyses, enabling the study of data by race/ethnicity, gender, discipline, and institution, although simultaneous disaggregation across all these dimensions can pose practical challenges, such as reducing individual groups to numbers too small to report without compromising confidentiality. Nevertheless, MIDFIELD's longitudinal data for each student address limitations inherent in cross-sectional data, offering a more comprehensive understanding of student experiences over time [43]. Although numerous studies have employed MIDFIELD, some are highlighted here to showcase the diverse methods adopted to address these disparities.

MIDFIELD has been used to study outcomes related to curriculum design and content, including a nuanced comparison of student performance in individual subjects relative to the other subjects [71] and how curriculum complexity varies among programs and over time [72]. Other curriculum-focused studies using MIDFIELD have focused on relating co-op participation to macroeconomic factors [73] and to academic and demographic variables [74]. Following a significant study of various outcomes for all engineering disciplines aggregated [46], various papers characterized student demographics and outcomes in specific engineering disciplines [75] – [77]. Other studies using MIDFIELD have focused on the experiences of specific populations such as women engineering students disaggregated by race/ethnicity [45], non-traditional students [78], Black transfer and non-transfer students [79], and rural students [80].

These selected studies collectively underscore the versatility and depth of insights derived from MIDFIELD datasets, demonstrating the intricate methodologies employed to navigate challenges posed by institutional and student differences in engineering education research. Despite its broad applicability to many U.S. engineering students enrolled in large public institutions, the use of uniform methods or analyses across institutions may yield unreliable conclusions. The variability in curricular requirements among different institutions introduces complexities that can significantly influence the courses taken by students, thereby affecting the interpretation of analyses [81]. Hence, a nuanced approach is essential, acknowledging the intricacies of multi-institutional datasets and the potential impact of institutional differences on research outcomes.

Planned analysis procedures

A few terms bear defining in that they will figure prominently in the design of the current study. A longitudinal study is an investigation that involves observing the same group over an extended duration in order to monitor evolving patterns [82]. Survival analysis is a statistical modeling method designed to handle the occurrence of events either frequently or temporal in a longitudinal dataset [83]. Hierarchical linear modeling uses data collected from nested levels to assess the impact of factors at both individual and group levels [84].

Survival analysis, so named because it was initially employed by biostatisticians to model time to mortality after specific treatments or diagnoses [85], was later adopted by social science researchers [83]. It has since experienced increasing use in investigating student persistence and dropout behavior, as evidenced by studies such as [86-89].

This study aims to contribute to the existing literature by employing a multilevel discrete-time survival analysis, specifically focusing on the hierarchical structure of student retention data within higher education institutions. While previous research has explored the impact of introductory mathematics courses on engineering student persistence, there is a notable gap in comprehensive, multilevel analyses, especially considering diverse institutions. Therefore, our research seeks to address this gap, providing a nuanced examination of the role of Calculus I in engineering student persistence across 22 educational institutions.

The selected institutions represent a diverse range in terms of size, location, and demographics, offering a robust foundation for understanding how the influence of Calculus I varies across different contexts. Our study addresses the challenges associated with censored observations by employing multilevel discrete-time survival analysis to handle incomplete pathways. This approach ensures a thorough examination of student persistence, emphasizing the unique contribution our research makes to the existing body of knowledge.

This study employs multilevel analysis in conjunction with discrete-time hazard rate models to investigate the inherent hierarchical data structure present in of student persistence data. Leveraging longitudinal data analysis, we utilize information gathered on subjects as a control, removing between-subject variation from the error and tracking changes in individuals over the course of the study. Longitudinal data offer valuable insights into changes occurring within subjects, enabling us to explore factors influencing students' decisions to persist or discontinue their college enrollment.

In this study, we will include covariates such as SAT scores, gender, and race/ethnicity to isolate the specific impact of Calculus I on engineering student persistence, ensuring a more accurate assessment of the relationship between academic integration and retention.

Our independent variable, Calculus I performance metrics obtained from MIDFIELD, is paired with longitudinal persistence data tracked over specified time points. This comprehensive data collection approach allows us to make the most of the existing data while examining persistence patterns at every time interval. The study employs multilevel discrete-time survival analysis for its appropriateness in capturing the hierarchical structure of the data and its event-based nature. Survival analysis is commonly modeled in terms of hazard models. Hazard modeling is characterized by the population hazard function, which outlines the risk of an event to occur in each time period [90].

Given the similarities among subjects arising from comparable environments and the consequent lack of independence among subjects, multilevel data analysis adeptly addresses this absence of independence [84]. In multi-level analysis, the initial level of data analysis can be formulated to account for effects across all levels, enabling the examination of potential interactions among the various levels of data [85].

Survival analysis has the capability to incorporate within-subject variables of data on enrollment status at various time points [91]. Discrete-time survival analysis is well-suited for examining longitudinal data, standing out as a suitable method for the thorough examination of longitudinal data, proficiently handling predictors, and efficiently managing censored observations [92].

While MIDFIELD provides a large dataset, variations exist among institutions and students. Despite adjustments for cross-institutional research, differences persist. The study will acknowledge the limitations of simultaneous disaggregation by race/ethnicity, gender, discipline, and institution. MIDFIELD's longitudinal data avoids issues common in cross-sectional data, allowing for more robust analyses.

While MIDFIELD captures experiences representative of U.S. engineering students [69], caution will be exercised in generalizing across all institutions. Differences in curricular requirements may influence course selection, potentially impacting analysis interpretations. Given the limitations of the MIDFIELD dataset, students transferred from other institutions are not included in the study because we have no record of their earliest coursework. Additionally, we won't be able to examine variables such as socio-economic level and financial aid high school GPA.

To explore persistence to graduation patterns, time points will be specified based on available information within the MIDFIELD dataset. These time points will extend from the end of each semester up to the conclusion of the sixth year, providing a comprehensive examination of students' trajectories. At each specified time point, the dataset will be analyzed to identify persistence patterns. When a student either drops out or successfully graduates, they will be excluded from analyses at subsequent time points. For instance, if X students drop out or graduate by the end of a semester, they will be removed from subsequent analyses, ensuring that the remaining students constitute the entire study cohort for subsequent persistence analyses.

The study will acknowledge the dynamic nature of student enrollment, and robust measures will be employed to handle attrition. The removal of students who exit the program will ensure that analyses reflect the evolving composition of the sample, contributing to the accuracy and relevance of the findings.

Conclusion

In conclusion, this study undertakes comprehensive exploration of the factors influencing engineering student persistence, with a particular focus on the impact of Calculus I. By adopting Tinto's Theory of Student Departure and Astin's Input-Environment-Output (I-E-O) model as foundational theoretical frameworks, we aim to uncover nuanced insights into the complex dynamics of academic and social integration within the context of diverse institutions. The utilization of multilevel discrete-time survival analysis ensures a meticulous examination of longitudinal data, capturing the hierarchical structure of the educational environment. It is important to note that this paper is presented as a proposal, with no empirical results yet obtained. It is anticipated that this research will contribute significantly to the existing body of knowledge on student retention in higher education by separating the individual and institutional factors related to the effect of Calculus I on persistence. The implications derived from our forthcoming findings will offer valuable insights applicable to both academic and institutional practices, providing essential information for educators, administrators, and policymakers.

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